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Suspension Bridges: A New System. By STILLMAN W. ROBINSON.

(Read before the Michigan Scientific Association.)

MR. EDITOR:—The following article is an abstract of a Thesis prepared by Mr. Robinson, and read before the Faculty just before taking the degree of Civil Engineer at the last commencement. It is due to him to say, that he had numerous verifications of the principal formulas, and several processes of reduction which I have omitted; but all the formulas here given are literally copied from his paper.

Professor Rankine, in his work on "Applied Mechanics," in speaking of the linear arch which is every where normally pressed, p. 190, says, "The only arch of this kind which has hitherto been considered, is the circular arch under uniform pressure." This example is illustrated by a circular ring placed horizontally under a fluid. He then gives a second example, p. 190, called the "Hydrostatic Arch," or "The Arch of Yvon-Villarceaux," where the arch is in a vertical plane and pressed externally by a fluid whose surface is horizontal. The investigations by Mr. Robinson, given in the following article, make another, or third example.

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In the ordinary suspension bridge, the tension is greatest at the piers and least at the middle.

My object is to deduce and discuss the equations for a suspension bridge when the suspension rods are so inclined as to produce a uniform tension throughout the cable; the bridge being loaded uniformly over the span. The analysis is founded upon the following theorems:

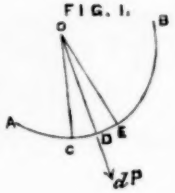
THEOREM I. *In a normally pressed arch the tension or compression is uniform throughout.*

For the tension from one point to another cannot differ unless there be a tangential component; but if all the forces are normal they cannot have any tangential component at the point where they act.

THEOREM II. *The pressure at different points varies inversely as the radius of curvature.*

Proof. Let A B, fig. 1, be any normally pressed arc, d P be any element of the normal force, and which may be considered the resultant of the tensions on each side of it.

FIG. 1.



C D = D E = $\frac{1}{2} ds$.

O D = ρ = the radius of curvature at D.

T = the stress along the arc.

a = an infinitesimal angle C O E.

Then, by Mechanics we have

$$dP = \sqrt{T^2 + T^2 - 2TT \cos. a} = 2T \sin. \tfrac{1}{2} a,$$

which at the limit equals T a.

$$\text{But } \rho a = ds \quad \therefore \quad dP = \frac{T\,ds}{\rho} \qquad . \qquad . \qquad (1)$$

which proves the theorem. By integrating (1) the first member between O and P; the second between O and 1, we have

$$P = \frac{T}{\rho} \quad \text{or} \quad T = P\rho_* \qquad . \qquad . \qquad (2)$$

hence, the tension equals the pressure per unit of length multiplied by the radius of curvature at the middle of that unit.

* It will be seen that Mr. Robinson has adopted the same method for finding an expression for the tension, that many writers use for finding the relation between the power and resistance, when a rope is coiled around a cylinder and friction is considered. If we should apply external normal forces just sufficient to remove the pressure on the cylinder, there would be no friction, and hence no loss of tension, which corresponds to Theorem I.

If P be the applied force, W the resistance at the other end of a rope coiled around a cylinder, a the arc at a unit's distance, and f the co-efficient of friction; we have (see Bartlett's Analytical Mechanics, 3d Ed., p. 382)

$$P = W e^{f}$$

in which if $f = 0$ we have P = W, which also corresponds with Theorem I.

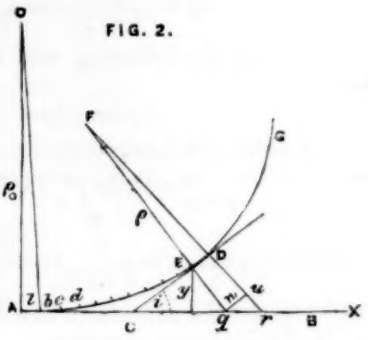
In the case of friction the tension varies, and if the cylinder be circular, the radius is constant; but in Theorem II., the tension is constant and the radius of curvature may or may not be constant. D.V.W.

Now let A G, fig. 2, represent the arc of the cable. Let A B be the axis of X; A O of y, w, the weight per unit of length over the span.

A O, F E and F D radii of curvature.

By Theorem I, the suspension rods must coincide in direction with the radii of curvature; hence if E D $= ds$; E q and D r may be considered two consecutive suspension rods. Through E, draw E C tangent to the curve, and through q a line parallel to the tangent.

FIG. 2.



Then let D C $x = i$ O A $= \rho_o$

$qr = m$ Radius F E $= \rho$

$qu = n$

Then $w\,m$ is the weight acting vertically on qr, and which resolved normally, is the normal pressure on E D, and equals

$$w\,m \text{ sec. } i = d\,\text{P}. \quad . \quad . \quad . \quad (3)$$

At A, $m = ds$ and $i = o$; hence the normal pressure at that point is

$$w\,ds. \quad . \quad . \quad . \quad . \quad (4)$$

Hence, from (1), (3), and (4), we have

$$\rho\,m \text{ sec. } i = \rho_o\,ds \quad . \quad . \quad (5)$$

$$\therefore \frac{ds}{m} = \frac{\rho}{\rho_o} \text{ sec. } i \quad . \quad . \quad . \quad (6)$$

By similarity of triangles

$$\rho : ds :: \rho + y \text{ sec. } i : n \text{ or } m \cos. i$$

$$\therefore \frac{ds}{m} = \frac{\rho \cos. i}{\rho + y \text{ sec. } i} \quad . \quad . \quad . \quad (7)$$

From (6) and (7) we find

$$\rho_o = (\rho + y \text{ sec. } i) \text{ sec.}^2 i \quad . \quad . \quad (8)$$

which is the equation of the curve in terms of the variables ρ, y, and i.

To find the equation when referred to rectangular co-ordinates, we substitute.

$$\frac{\left(1+\frac{dy^2}{dx^2}\right)^{\frac{3}{2}}}{\frac{d^2y}{dx^2}} \text{ for } \rho \text{ and } \sqrt{1+\frac{dy^2}{dx^2}} = \sqrt{1+\text{tang.}^2 i} \text{ for sec. } i \text{ and}$$

(8) becomes

$$\left(1+\frac{dy^2}{dx^2}\right)^{\frac{3}{2}} + y\left(1+\frac{dy^2}{dx^2}\right)^{\frac{3}{2}}\frac{d^2y}{dx^2} = \rho_o \frac{d^2y}{dx^2} \quad . \quad . \quad (9)$$

$$\text{Make } \frac{dy^2}{dx^2} = 2z \qquad \therefore \frac{d^2y}{dx^2} = \frac{dz}{dy}$$

and (9) becomes

$$dy + \frac{y\,dz}{1+2z} = \rho_\circ \frac{dz}{(1+2z)^{\frac{5}{2}}}$$

This is of the following well known form, usually called a linear equation.

$$dy + \mathrm{x}\,y\,dx = \mathrm{x}_1\,dx,$$

of which the integral is

$$y = e^{-\int \mathrm{x}\,dx} \int e^{\int \mathrm{x}\,dx}\,\mathrm{x}_1\,dx \quad . \quad . \quad (10)$$

Observing that $\mathrm{x} = \frac{1}{1+2z}$ and $\mathrm{x}_1 = \frac{\rho_\circ}{(1+2z)^{\frac{5}{2}}}$, and using dz for dx in (10), because the expression is a function of z, not of x, and substituting in (10) and reducing gives

$$y = \frac{1}{\sqrt{1+2z}}\left(-\frac{\rho_\circ}{2(1+2z)} + \mathrm{c}\right)$$

But $y=0$ and $2z=0$ for $x=0$ $\quad \therefore \quad \mathrm{c} = \frac{1}{2}\rho_\circ$,

$$\therefore\ y = \frac{\rho_\circ}{2}\left(\frac{1}{(1+2z)^{\frac{1}{2}}} - \frac{1}{(1+2z)^{\frac{3}{2}}}\right)$$

$$\text{or } (1+2z)^{\frac{3}{2}} = \frac{z\rho_\circ}{y}^{*} \quad . \quad . \quad . \quad (11)$$

For convenience, make $2z = u^2 = \frac{dy^2}{dx^2} = \tan^2 i$ . . (12)

$$\therefore\ (1+u^2)^{\frac{3}{2}} = \frac{u^2\rho_\circ}{2y} \quad . \quad . \quad . \quad (13)$$

With (9), (12), and (13) eliminate y, dy, and d^2y, and we have

$$(1+u^2)^{\frac{5}{2}} + \frac{\rho_\circ u^2}{2}\frac{du}{dx} = \rho_\circ \frac{du}{dx}$$

$$\therefore \frac{dx}{\rho_\circ} + \frac{u^2 du}{2(1+u^2)^{\frac{5}{2}}} = \frac{du}{(1+u^2)^{\frac{5}{2}}} \quad . \quad . \quad (14)$$

which by integration becomes

$$\frac{x}{\rho_\circ} + \frac{1}{2(1+u^{-2})^{\frac{3}{2}}} = \frac{1}{(1+u^{-2})^{\frac{1}{2}}}$$

$$\text{or } \frac{x}{\rho_\circ}(1+u^2)^{\frac{3}{2}} + \frac{u^3}{2} = u(1+u^2) \quad . \quad . \quad (15)$$

Substitute $(1+u^2)$ from (13) and reducing will give

$$u^3 - u\frac{x}{y} = -2$$

* If in (11) we substitute $z = \frac{1}{2}\frac{dy^2}{dx^2}$ and reduce, we will obtain a differential equation between x and y, of the form of a complete cubic equation, which form is inconvenient even if it has a possible solution. Hence he obtains another equation between x and u and then eliminates u. D.V.W.

$$\therefore u = \frac{x}{2y} \pm \sqrt{\left(\frac{x}{2y}\right)^2 - 2} \quad . \quad . \quad . \quad (16)$$

which in (13) gives

$$\left[1 + \left(\frac{x}{2y} \pm \sqrt{\left(\frac{x}{2y}\right)^2 - 2}\right)^2\right]^{\frac{3}{2}} = \left[\frac{x}{2y} \pm \sqrt{\left(\frac{x}{2y}\right)^2 - 2}\right]^2 \frac{\rho_\circ}{2y} \quad (17)$$

which is the equation required, but it is too complex to be of *practical* use. By using the variable i, we obtain more convenient forms. Thus from (12) and (13) we obtain

$$y = \tfrac{1}{2}\rho_\circ \sin.^2 i \cos. i \quad . \quad . \quad . \quad (18)$$

Similarly from (12) and (15)

$$x = \rho_\circ (\sin. i - \tfrac{1}{2}\sin.^3 i) \quad . \quad . \quad (19)$$
$$= \tfrac{1}{2}\rho_\circ (1 + \cos.^2 i) \sin. i$$

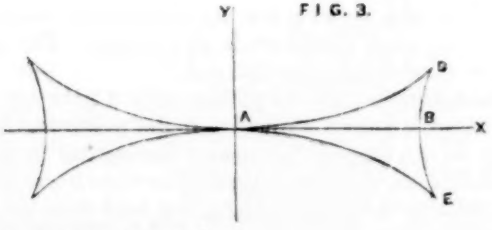
From (8) and (18)

$$\rho = \rho_\circ (1 - \tfrac{3}{4}\sin.^2 i) \quad . \quad . \quad (20)$$

From (18) and (19) we obtain the following table of co-ordinates for $\rho_\circ = 100$.

For $i = 0$	$y = 0\cdot$	$x = 0\cdot$
$i = 10°$	$y = 1{\cdot}485$	$x = 17{\cdot}096$
$i = 20°$	$y = 5{\cdot}495$	$x = 32{\cdot}200$
$i = 30°$	$y = 10{\cdot}825$	$x = 43{\cdot}350$
$i = 40°$	$y = 15{\cdot}825$	$x = 50{\cdot}998$
$i = 50°$	$y = 18{\cdot}860$	$x = 54{\cdot}132$
$i = 54°\ 44'\ 7''$	$y = 19{\cdot}446$	$x = 54{\cdot}430$
$i = 60°$	$y = 18{\cdot}750$	$x = 54{\cdot}210$
$i = 70°$	$y = 15{\cdot}100$	$x = 52{\cdot}480$
$i = 80°$	$y = 8{\cdot}421$	$x = 50{\cdot}625$
$i = 85°$	$y = 4{\cdot}480$	$x = 50{\cdot}200$
$i = 90$	$y = 0{\cdot}000$	$x = 50{\cdot}000$

FIG. 3.



with these, fig. 3 is constructed.

Discussion of the Curve.

1. From (18) and (19) we see that for the same values of i, x and y vary directly as $\rho_\circ$; hence if a table be made as above, for $\rho_\circ = 1$, they may be found for any other value of $\rho_\circ$, by simply multiplying the values in the table by that value.

2. To find the maximum values of x and y, differentiate (18) and (19), and place equal zero. From either we get

$$\sin. i = \sqrt{\tfrac{2}{3}} \qquad \cos. i = \sqrt{\tfrac{1}{3}} \quad . \quad . \quad (22)$$

or $i = 54° 44' 7''$; hence both are maximum at the same point.

3. From (20) ρ is positive, for $\sin.^2 i$ less than $\frac{2}{3}$ and negative for $\sin.^2 i$ greater than $\frac{2}{3}$, and zero for $\sin.^2 i$ equal $\frac{2}{3}$. For $i = 90$; $\rho = \frac{1}{2}\rho_o$.

4. From the preceding results we infer that there may be a cusp. Applying the test we first find from (18), (19), and (22) that

$$\frac{dy}{dx} = \frac{0}{0} \text{ for } i = 54° 44' 7''$$

Substitute (22) in (18) and (19) and we have

$$x = \tfrac{2}{3}\rho_o\sqrt{\tfrac{2}{3}} \qquad y = \tfrac{1}{3}\rho_o\sqrt{\tfrac{1}{3}} \quad . \quad . \quad . \quad (23)$$

$\therefore \quad \frac{x}{2y} = \sqrt{2}$ which in (17) gives an identical expression; also in (16) gives $u = \pm\sqrt{2}$.

Hence the first conditions are fulfilled. Now give increments to these values of x and y in (16) and it becomes imaginary; and by subtracting decrements, it remains real; hence there is a cusp at the point whose co-ordinates are given in Equation (23).

5. From (23) we have $\frac{x}{y} = 2\sqrt{2}$, which being constant shows that the ratio of x and y for the maximum is independent of the loading or ρ_o.

6. Because there are two angles corresponding to every sin. and cosin.; therefore from (18) and (19) it appears that the curve is symmetrical in respect to both x and y. Hence there are four cusps, as shown in fig. 3.

7. To find where the curve cuts the axis of x, make $y = 0$ in (18), which gives cos. $i = 0$ or $\sin.^2 i = 0$. For the latter $i = 0$, which is at the origin; for the former $i = 90°$; which in (19) gives

$$x = \pm\tfrac{1}{2}\rho_o \quad . \quad . \quad . \quad . \quad (23a)$$

It may be asked why x and y are not continually increasing functions of each other, as in the parabola or catenary. The original premises will throw some light upon this point.

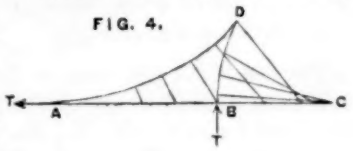
It will be remembered that the portion of w x between two radii of curvature produced, resolved normally, is the pressure. Now the further the curve be prolonged, the nearer horizontal is the radius of curvature, and if it could be prolonged so as to be horizontal, it would touch x at an infinite distance, making the load and hence the pressure infinite, also the tension infinite, which would not be consistent with Equation (2), unless the radius of curvature at the middle be infinite, which can be the case only when the curve becomes a straight line. From this popular reasoning we would conclude that the curve must return upon itself.

8. Equation (2) shows that when ρ is negative, the tension is negative, or otherwise it is compressive. This will enable us to explain the facts which pertain to the arc D B. After passing the cusp the arc is

concave to the force, (see fig. 4); hence it is compressive, but uniform and equal to the tension on the preceding part. By the curve returning as it does, the radius of curvature may become horizontal without intercepting an infinite amount of X. The exact value is hereafter shown to be $\rho_\circ$, see Equation (26*a*), hence the weight on this portion is $w\,\rho_\circ$, an amount equal the tension of the cable. See Equation (2).*

9. It will thus be seen, that if we have a chord A D, fig. 4, to resist tension, and a rod D B, to resist compression, bent into the proper curve, and forces T applied as in the figure, and a series of chords arranged normally, attached to a system of weights uniformly distributed over X, and a sufficient horizontal force applied at C to keep the chords normal; then will the combination remain in equilibrium.

FIG. 4.



10. *Length of Arc.* By calculus

$$ds = \frac{dy}{\sin. i}$$

Differentiate (18), substitute and reduce, gives

$$ds = \frac{\rho_\circ}{4}(1 + 3\cos. 2i)\,di$$

$$\therefore\ s = \tfrac{1}{4}\rho_\circ\,(i + \tfrac{3}{2}\sin. 2i) + c$$

But

$$s = 0 \text{ for } i = 0 \qquad \therefore\ c = 0$$

hence for both branches we have

$$2s = \tfrac{1}{2}\rho_\circ\,(i + \tfrac{3}{2}\sin. 2i) \qquad . \qquad . \qquad (24)$$

in which i is a linear quantity. If it be given in degrees, we use

$$\frac{\pi\, i}{180}$$

$$\therefore\ 2s = \tfrac{1}{2}\rho_\circ\left(\frac{\pi\, i}{180} + \frac{3}{2}\sin. 2i\right) \qquad . \qquad . \qquad (25)$$

The limits for AD are 0° and 54° 44′ 7″; for D B the limits are 54° 44′ 7″ and 90°.

For $i = 45°$, we have

$$2s = \rho_\circ \times 1{\cdot}14 +$$

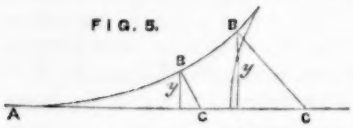
From (25) we see that a table whose argument is i, might be made, and calling $\rho_\circ = 1$, we could find s for any other value of $\rho_\circ$ by simply multiplying by the assumed value.

* As the tension at A and C are horizontal, equal, and opposite, and the load acts vertically downward, and the tension at B vertically upward; we would infer from the principle of parallel forces that T = *w* A C, or from eq. (26*a*) T = $w\,\rho_\circ$ as above.

We see from (23*a*) and (26*a*) that B is midway between A and C; hence the whole system will balance upon B as a fulcrum, the same as if the roadway were perfectly rigid. D.V.W.

10. *To get an expression for* A C, *or one-half the span of a bridge.* See fig. 5.

FIG. 5.



Let AC = B

$\therefore$ B = $x + y$ tang. i,

or combining with (18) and (19), we obtain after reduction,

$$B = \rho_\circ \sin. i \quad . \quad . \quad . \quad . \quad (26)$$

At the cusp sin. $i = \sqrt{\frac{2}{3}}$ $\quad \therefore$ B = $\rho_\circ \sqrt{\frac{2}{3}}$

For $i = 90°$ $\quad B = \rho_\circ \quad . \quad . \quad (26a)$

If it be desired to attach the ties at equidistant points on the roadway, make B = b', $2b'$, $3b'$, &c. in (26), and substitute the value of i thus formed in (25), and the points of attachment on the cable will thus become known.

11. *Length of the Ties.* Let l = BC, = the length of any one. Then, Fig. 5, and Eq. (18) give $l = y \sec. i = \frac{1}{2} \rho_\circ \sin.^2 i \quad . \quad (27)$

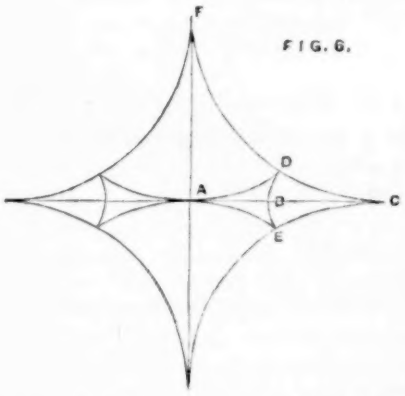
which with (26) becomes = $\frac{B^2}{2\rho_\circ}$ for the last tie.

12. *The Evolute of the Curve*, fig. 6.

Let x_1, and y_1, be the co-ordinates of any point of the evolute, then we readily have;

$$x_1 = x - \rho \sin. i$$
$$y_1 = y + \rho \cos. i$$

FIG. 6.



These with (8), (19), and (20) give by eliminating x, y, ρ. sin.i and cos. i;

$$y_1^{\frac{2}{3}} + x_1^{\frac{2}{3}} = \rho_\circ^{\frac{2}{3}}$$

which is the equation of a hypocycloid, when the radius of the generating circle is one-fourth that of the directing one*. It is represented in fig. 6.

The curve is symmetrical with X and Y, and with axes inclined 45° to X and Y.

13. *Tension of the ties.* Suppose the ties are so distributed that the tension on each shall be equal, then it is required to find the points of attachment.

* This equation is deduced from a variety of problems, see Mathematical Monthly, vol. 1, p. 133.

Equation (17), or (18) and (19), are the equations of the involute of the hypocycloid, but the involute touches the evolute at the points given by eq. (23). The radius of the directing circle in this case would be $\rho_\circ$; of the generating circle $\frac{1}{4} \rho_\circ$.

We here have an easy mode of determining the length of the evolute FC, fig. 6. For FD evidently equals FA = $\rho_\circ$ and DC = BC = $\frac{1}{2} \rho_\circ$ (see 23*a*); hence the total length is $\frac{3}{2} \rho_\circ$, which agrees with other modes of solution.

By means of eqs. (18) and (19), we find the area ADBA to be

Let d P = the amount of normal pressure on an element ds.

Then from (3) we have, considering B as variable, and using d B for $m\,d$ P $= w\,d$ B sec. i.

But from (26) dB $= \rho_\circ \cos. i\,di$

$$\therefore d\,\text{P} = w\rho_\circ\,di \text{ or } \text{P} = w\,\rho_\circ i \quad . \quad . \quad (28)$$

for the total normal pressure on one side. We see P varies as i.

Now assume the number of ties on half of one cable; say N; the tension on each will be P ÷ N; so for the first tie we have $\frac{\text{P}}{\text{N}\,w\,\rho_\circ} = i$, and this value of i in (24) will give s.

Substitute $2i$, $3i$, $4i$, &c. in (24), and we may find s for the 2d, 3d, 4th, &c., ties. The same in (26) gives the points of attachment to the roadway.

From the origin to the cusp, $\text{P} = w\,\rho_\circ \times 0{\cdot}955+$

" " " intersection with X, $\text{P} = \frac{1}{2}\pi w\rho_\circ$

Hence the total normal pressure to the cusp is nearly equal the tension of the cable; and to the intersection with X, it is more than $1\frac{1}{2}$ times the tension.

14. *Horizontal Stress along the Roadway.*

An element of the horizontal force is d H $= wd$ B tang. i.

Find tang. i from (26) and substitute gives

$$d\,\text{H} = \frac{w\,\text{B}\,d\,\text{B}}{\sqrt{\rho_\circ{}^2 - \text{B}^2}}$$

$$\therefore \quad \text{H} = w(\rho_\circ - \sqrt{\rho_\circ - \text{B}^2}) \quad . \quad . \quad (29)$$

$$\text{Area} = \int y\,dx = \tfrac{1}{2}\rho_\circ{}^2 \int \left(\sin.^2 i \cos.^2 i - \frac{3}{2}\sin.^4 i \cos.^2 i\right) di$$

$$= \tfrac{1}{2}\rho_\circ{}^2 \left\{ \cos.i \left[\frac{1}{32}\sin.i + \cos.^2 i \sin.i \left(\frac{1}{4}\sin.i - \frac{1}{16} \right) \right] + \frac{1}{32}\sin.^{-1} x \right\}$$

For the area to a vertical ordinate through D, the limits are $i=0$ and $\sin.i = \sqrt{\frac{1}{3}}$

$\therefore$ the area $= \rho_\circ{}^2 \times 0{\cdot}03047+$

For the total area ADB, the limits are $i=0$ and $i=90$

$$\therefore \quad \text{area} = \frac{1}{128}\pi\,\rho_\circ{}^2$$

For the area DAFD + DBCD, we may use the polar equation of the area;

$$\int \tfrac{1}{2}\rho^2 di \text{ which with (20) gives}$$

$$\tfrac{1}{2}\rho_\circ{}^2 \int \left(1 - 3\sin.^2 i + \frac{9}{4}\sin.^4 i\right) di$$

$$= \tfrac{1}{2}\rho_\circ{}^2 \left(\frac{11}{32}i + \frac{3}{16}\sin.2i + \frac{9}{128}\sin.^4 i\right)$$

which between the limits $i=0$ and $i=\frac{1}{2}\pi$ gives area DAFDBCD $= \frac{11}{128}\pi\,\rho_\circ{}^2$

Hence, the total area AFCÁ is

$$\left(\frac{1}{128} + \frac{11}{128}\right)\pi\,\rho_\circ{}^2 = \frac{3}{32}\pi\,\rho_\circ{}^2$$

a result which also agrees with the direct solution. D.V.W.

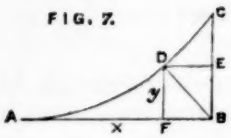
Observing that $H=0$ for $B=0$ $\quad\therefore\quad C=w\rho_\circ$

Between the origin and cusp $H=w\rho_\circ\times 0{\cdot}423+$.

This force is resisted either by compression in a rigid roadway, or by tension by fastenings at the ends. In the former the stress is greatest at the middle; in the latter, at the ends.

15. *To find $\rho_\circ$ when the span and deflection are given.*

FIG. 7.



Let $A=BC=$ height of the pier, fig. 7.

$B=AB$; $y=DF$; $x=AF$.

We have

$$B-x=y\tan.\ i.$$

which with (26) gives

$$B-x=\frac{By}{\sqrt{\rho_\circ{}^2-B^2}}$$

From the fig. $(B-x)^2=y(A-y)$; eliminating $B-x$ and reducing,

$$\text{gives } \rho_\circ{}^2-B^2=\frac{\rho_\circ{}^2 y}{A}$$

From (18) and (26) $\quad y=\dfrac{B^2}{2\rho_\circ}\sqrt{\rho_\circ{}^2-B^2}$

By eliminating y, and reducing, we have

$$\rho_\circ=\frac{B}{2A}\sqrt{B^2+4A^2} \qquad . \qquad . \qquad (30)$$

16. *Tension of the Cable.*

From (1) and (30)

$$T=w\rho_\circ=\frac{wB}{2A}\sqrt{B^2+4A^2}$$

which is identical with the expression for the tension at the pier heads of the ordinary suspension bridge, when the cable is the arc of a parabola. In the expression $T=w\rho_\circ$, T is independent of the span; hence the tension is the same for all spans, if $\rho_\circ$ and the load per unit of length remain the same.

17. *Total length of the cable between the pier heads.*

In fig. 7, $CD=(B-x)\sec.i$

From (19) and (26) $\quad x=B-\dfrac{B^3}{2\rho_\circ{}^2}$

$$\therefore\ 2CD=\frac{B^3}{\rho_\circ{}^2}\sec.i.$$

which with (24) gives

$$2AC=L=\tfrac{1}{2}\rho_\circ\left(i+\frac{3}{2}\sin.2i\right)+\frac{B^3}{\rho_\circ{}^2}\sec.i \qquad . \qquad . \qquad (31)$$

which, with (26) and (30), will give L in terms of A and B.

The balance of the paper consists of remarks upon the relative merits of the system.

On the Construction of Wrought Iron Lattice Girders.

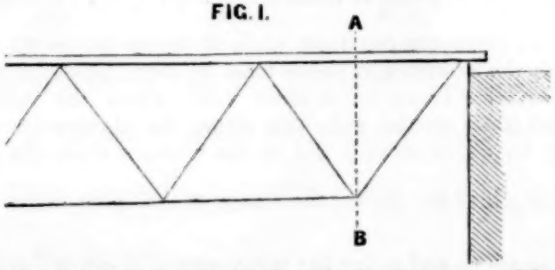
By Thomas Cargill, C. E.

From the Lond. Civ. Eng. and Arch. Journal, Jan., 1863.

(Continued from page 90.)

In treating of the strains on the webs, or lattice sides, of the girder, it is proposed, first, to deduce some general formulæ from those already given for the strains on the booms, and afterwards to reduce them to such a form as will prove practically useful in the designing of girders belonging to this particular class, in which the depth equal $\frac{1}{12}$ of the span, and which is also the most economical ratio in girders of the lattice construction, with respect to quantity of material required. The relative position of the strains on the webs and on the booms are precisely opposite; the maximum strains on the former occurring at the ends of the girder over its bearings on the abutments, and those on the latter taking place at the centre, both being considered under the conditions of a uniform load. This condition gives the absolute maximum strain which can by any possibility come on the booms, but does not produce the same action on certain portions of the webs, which are more or less affected by the actual position of the moving load, with the exception of the end bars, which whether ties or struts receive the greatest amount of strain, like the booms when the girder is uniformly loaded. In practice it will be found generally more advantageous to make the last bar, or that terminating immediately over the abutment, a strut, instead of a tie, especially if the ends of the girder be constructed with pillars and openwork, instead of solid end plates, as by that means the effects of the leverage resulting from the use of a tie are reduced to a minimum. An example of ending a girder with a tie is shown in Fig. 1, which is a skeleton diagram, representing the end portion of one of the girders of the Crumlin Viaduct. The beams constituting the structure are not lat-

FIG. I.



tice, but triangular beams of the description known as Warren's patent, and include a considerable quantity of cast iron in some of their parts. They are supported on the abutments as shown in the diagram, and rest altogether on a top flanch, a mode of bearing not to be met with in any structure of a similar nature, and which imparts to them, to say the least, rather a ricketty and insecure appearance.

If circumstances should ever render such a method of suspension imperative, the girder might still be made to terminate by a strut, by

substituting a strong pillar in the dotted line A B; it would be preferable, however, to use the simple plan of resting the girder in the ordinary manner on the abutment, which affords a more uniform and steady bearing than that described; the chief objection to which is that it confines the bearing too much to one particular spot.

From what has been said with respect to the strains on the booms, it appears that they vary increasingly with the distance from the abutments, and follow a more complicated rule than those on the web, which vary inversely at this distance. For let S = strain on booms at centre, and S_1 strain at any other point which divides the boom into segments a and b; putting L for the span, we have

$$S_1 = \frac{S \times 4\,ab}{L^2}.$$

In investigating the strains on the web, we shall first consider the case of a lattice girder in its simplest form—viz: as a triangular girder, with but one series of triangles. To take the instance of a weight at the centre; on the usual supposition that one-half of this weight is transferred to each abutment, it is evident that the strain upon the last bar $= \frac{W}{2} \times$ cosec θ, putting W for the weight at centre, and θ for the angle of the diagonals with the booms (see Fig. 2). Neglecting the weight of the girder itself, or supposing it, which is the same thing, to be included in W, no other strain is brought upon any of the diagonals except what they undergo in transferring $\frac{W}{2}$ from the centre to the abutments; so that the strain is uniform upon every one of them, and is given by the equation

$$S = \frac{W}{2} \times \text{cosec } \theta \quad . \quad . \quad . \quad (1)$$

As these strains are constant, while those on the booms commence at or near the abutments, there must be some point on the booms where the strains cross, or in other words where the strains on the boom equal those on the web, and where we might write the above expression for either strain; if a be the distance from the abutment, and D the depth of the girder, the strain on the boom varies as $\frac{a}{D}$, and putting S as above and S_1 for the latter strain, $S_1 = S \times \frac{a}{D}$ and reducing from the diagonal to the perpendicular

$$S_1 = S \times \frac{a}{D} \times \text{sin. } \theta \quad . \quad . \quad . \quad (2)$$

If W be the weight at the centre, the resulting strain on the boom at that point is $\frac{W\,L}{4\,D}$, and at any point at the distance a from the abut-

ment, the ratio being as $a : \frac{L}{2}$, we have $s_1 = \frac{W\,a}{2\,D}$ which is identical with equation (2). This method premises that the strain at the centre exceeds that on the web, or

$$\frac{W\,L}{4\,D} > \frac{W}{2} \times \text{cosec } \theta.$$

If it be required to obtain the distance from the abutment at which the strains are equal, we have only to equate the two formulæ

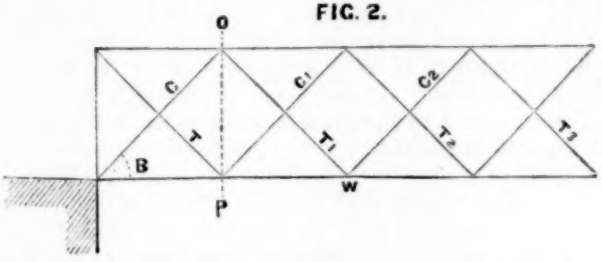
$$\frac{W\,a}{2\,D} = \frac{W}{2} \times \text{cosec } \theta,$$

from which we obtain $a = D \times \text{cosec } \theta$.

To return to the strains on the web under an uniform load W: the strain on the end bar will equal as in the former example $\frac{W}{2} \times \cos. \theta$.

If we now suppose the abutment shifted to the line O P (see fig. 2), so as to shorten the span, but keeping the value of W constant, the strain on the bar C_1 will be the same as on the former bar; as W is the uniform load, on restoring the abutment to its original position, it is clear that the strain on the last bar is increased by so much of W as covers the increased span, and therefore the strain on the bar C_1, as the second bar will be equal to that on the bar C minus this additional weight.

FIG. 2.



Make this weight $= w$, then $S = \frac{W}{2} \times \text{cosec } \theta - w \text{ cosec } \theta$. If a be the distance of the bar C_1, or any other diagonal from the abutment, we shall have

$$w = W \times \frac{a}{L} \text{ and } S = \left(\frac{W}{2} - \frac{W\,a}{L}\right) \times \text{cosec } \theta.$$

and reducing out we find

$$S = W\left(\frac{L - 2a}{2\,L}\right) \times \text{cosec } \theta \quad . \quad . \quad (3)$$

Our equation for the strain on any point of the booms is $a = \frac{W\,a\,b}{2\,D\,L}$, and equating this with the last formula, we have

$$\frac{W\,a\,b}{2\,D\,L} = W\frac{(L - 2a)}{2\,L} \times \text{cosec } \theta,$$

and we find for a,

$$a = \frac{(\text{L} - 2a)\,\text{D} \times \text{cosec}\ \theta}{b} \text{ but } b = \text{L} - a$$

so finally

$$a = \frac{(\text{L} - 2a)\,\text{D}}{\text{L} - a} \times \text{cosec}\ \theta\ ;$$

at this point, when a has this value, the strains on the booms and web are of the same amount. If S be the strain on the web at any point at a distance of p from the abutment, S_1 the corresponding strain on the boom, we shall have

$$\text{S} = \frac{\text{S}_1 \times (\text{L} - 2p)\,\text{D}}{p\,(\text{L} - p)} \times \text{cosec}\ \theta.$$

In applying these formulæ to a double lattice girder of one series of triangles, it must be remembered that the actual strains will only be one-half of those given by the above equations; this will be apparent at once by looking at any of the sections of a girder already given. If we make M the strain on the end bars, we shall have for that on any other part of the web

$$\text{S} = \text{M} \times \frac{(\text{L} - 2a)}{\text{L}}$$

Throughout the whole web of a lattice girder the compression and tension bars are strained equally in pairs, and the manner in which the load is distributed determines which pairs undergo strains of the same amount, although of an opposite character; the difficulty of distinguishing the similarly strained pairs of diagonals is limited to finding the first pair, and to the consideration of the action of the weight situated nearest the abutment; to explain this it will be simplest to take the usual method of investigating this question, which is to suppose the uniformly distributed weight to be equally divided at each junction of the diagonals with the flanches, and placed either at the top or bottom apices of one series of triangles. In fig. 2, confining our attention to the series of triangles composed of the diagonals $\text{C}\,\text{T}_1\,\text{C}_2\,\text{T}_3$, let the weight be at the bottom, and let W be the portion of the equally divided weight supposed to be acting at the junction of the diagonals T_1 and C_2 with the bottom flanch; W produces a tensile strain on T_1 and a compressive on C the end bar of the web; C receives no other strain but what is transmitted to it through T_1 and is therefore equally strained with it, and C and T_1 form the first pair with the weight distributed over the bottom part of the girder. Theoretically speaking there will be a small strain on C due to the portion of weight of the top member of the girder which may be supposed to rest on the junction of bars T_1 and C at the top flanch, but this will bear so very small a proportion to the other that it may practically be disregarded and the total weight considered as situated on the bottom boom, and consequently the strains on the two bars T_1 and C equal in amount. 2nd, let the weight be distributed over the top and let W be placed at the point O (see fig. 2), it will produce compressive strains

in both the diagonals C and T_1, but very disproportionate to one another; the equality of strain is thus at once destroyed, and we may take the bars T_1 and C_2 as the first pair in this instance, without it being necessary to show that the contrary strains in T_1 C_2 (by which is meant the compressive strain in the former and the tensile strain in the latter bar, these bars being respectively in tension and compression) balance one another, and that the strains resulting from the action of the remaining part of the weight are equal. The position of the load or manner in which the total weight is supposed to be distributed determines the correct value of the quantity *a* in the formula given above; if the weight be at top, *a* should be measured along the bottom and *vice versâ;* in the majority of cases the weight is neither wholly at top nor bottom, and it would be better to consider half of it on each boom respectively, and measured *a* to the middle point of the diagonal; wherever it is necessary to assume one or other of the above cases, the best plan will be to first discover which diagonals form pairs as just described, and to measure *a* from their junction at the booms. The simplest theoretical form of a lattice girder, whether double or single, is shown in fig. 1, and the important practical point is the subdivision of the web or the number of series of triangles which should be introduced; if there are not a sufficient number of crossings, the web will be deficient in stiffness, and require the aid of vertical irons to give it rigidity, whereas the web of a double lattice girder should possess sufficient rigidity in itself to be able to dispense with such assistance; if there be more crossings than what are necessary, a considerable number of the diagonals near the centre will have unavoidably a superfluous amount of strength, and consequently there will be a loss of metal, to say nothing of the extra quantity of workmanship in the shape of riveting, packing pieces, &c.

A distinction must here be made between that class of girders whose webs consists solely of diagonals both compressive and tensile, of a plain bar section, and whose strength depends altogether on the number and frequency of their intersections; and the other class whose webs are designed on correct principles which apportion to each separate diagonal its proper form (according to the nature of the strain it has to resist), its proper strain, and corresponding scantling. In the first examples of girders constructed upon the lattice principle, it was natural that such errors should exist, but notwithstanding that the true principles have been long since determined, bridges designed on the former faulty system are still erected. It will be apparent to any one who observes attentively a lattice girder of about 70 or 80 feet in span, constructed on the old system, and considers the frequent repetition of the crossings of the bars, taking place often at a distance of only 2 or $2\frac{1}{2}$ feet, and the immense amount of unnecessary riveting and workmanship which they involve, that, independent of other considerations, it would be far preferable and a great deal more economical to make use of the plate or other form. The fact of employing plain bars for both compressive and tensile strains, necessitates a considerable number of crossings, as the diagonals have no

strength to resist any strain in a direction out of the plane of the web; and were they not thus supported, those in compression would fail through flexure long before their ultimate strength was reached. As the strains are equal upon every pair of ties and struts, it is not at first sight apparent why a greater degree of stiffness is required in the latter than in the former; the reason will be plain if we consider the nature of the forces acting upon them and the relative states of equilibrium they are both in; it will be found that the ties are in a state of stable and the struts in a state of unstable equilibrium, for suppose them to be both deflected by any force out of the plane of the web, then the normal strain upon the strut acts in concert with this force, and has a tendency to increase the deflection already produced; the strain upon the tie has quite a contrary effect, as it tends to resist the force producing deflection and to restore the tie to its former position, or in other words to pull it straight again. It is manifest from this, that no strut ought to be unsupported beyond a certain portion of its length, which will vary with its form and sectional area, but it would be quite a mistake to use this as an argument exclusively in favor of the continuous web or close lattice system, as practice and experience have shown that unsupported struts properly proportioned, of a length equal to the depth of the web of any girder yet constructed might be used with safety—whether judiciously or economically is another point.

In deducing the strains upon the web of a lattice girder we have hitherto considered it in its simplest theoretical form, that of a triangular girder, or of a lattice girder with only its primary series of triangles, as they may be termed; we shall now proceed to consider what effect the introduction of one or more secondary series has upon the strains. It will be premised here that in a properly constructed web of a lattice girder no more crossings or secondary series of triangles will be introduced than what are necessary to fulfil the following condition—viz: to subdivide the struts and ties in a manner so as to impart such a degree of stiffness and rigidity to the web, that it may not require the aid of vertical stiffening irons to maintain it in its proper form, and also to multiply the points of junction of the diagonals with the top and bottom flanches sufficiently to admit of the employment of the ordinary rivets as the means of attachment; if necessary, rivets of a larger diameter than what are used in other portions of the girder may be employed, but it would be better to keep them all of the same size, especially if the girder has to be put together out of the workshop. The distance between any two intersection of diagonals will generally be determined by this latter requirement, as the former, or subdivision of the bars into short lengths, will follow as a necessary consequence. Let fig. 3 represent the skeleton diagram of a lattice girder, in which the primary series of triangles is shown by the darker diagonal lines; making use of the usual notations we have for the strain on the bar C,

$$S = W \frac{(L - 2a)}{4L} \times \operatorname{cosec} \theta.$$

In the same manner, if instead of supposing the weight uniformly distributed over the whole girder, we take it as equally divided among the apices of the primary triangles; putting N for the number of apices, we shall have for the same bar

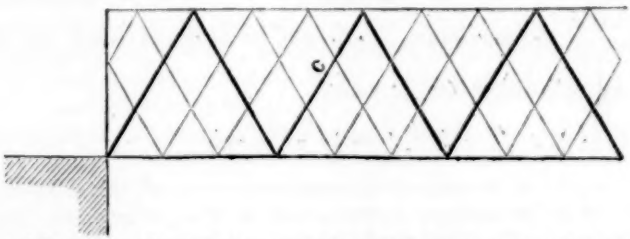
$$S = W \frac{(N-2)}{2N} \times \text{cosec } \theta.$$

By introducing secondary triangles it will be seen that the weight becomes still further divided, and the value of W for each apice less in exact proportion to the number of series of triangles, and consequently the strain resulting from it will be decreased in the same ratio. If N be the whole number of series of triangles, we shall find for the strain on any bar

$$S = W \frac{(L-2a)}{4L \times N} \times \text{cosec } \theta \quad . \quad . \quad (4)$$

We thus observe that the strain on the bar C is only affected by that portion totally uniformly distributed load which may be assumed to come directly upon the bars comprising its own series of triangles, and not by the remaining portion, which is supposed to act at the other points of attachment of the web and flanches; there is a slight

FIG. 3.



strain arising from the riveting together of the diagonals at their crossings, and where they are of frequent occurrence it should be taken into consideration, but as we have chosen a description of web where the crossings are reduced to a minimum, the additional strain brought in consequence either upon the booms or lattices themselves, may be safely disregarded, as even in the most extreme cases it would be practically of no importance and would be amply covered by the margin of extra strength always allowed. Except that it is always well to be on the safe side, a rather higher constant might be taken for the web, for two reasons—1st, because the bars are of superior iron; and 2d, because their strength is not impaired by the repeated insertion of rivets; the tension bars might with perfect safety be trusted with a working strain of five tons to the square inch of net section. Applying the general formula for the strain on any diagonal at a distance *a* from the abutment, we find for girders in which $D = \frac{L}{12}$, using the same notation as before,

$$S = 3 \frac{(L-2a)}{8 \times N \times L} \times \text{cosec } \theta.$$

If l = length of any lattice bar, cosec $\theta = \frac{l}{D} = 45°$, which is the proper angle of the lattice girder, being the most economical in practice, and also closely approaching that given by theory. The fraction $\frac{l}{D}$ being a constant, if the weight of the girder be neglected, an increase of D causes no increase in the strains on the web; the actual effect produced by an increased value of D is an addition to the weight of the girder by increasing the length of all the diagonals, and consequently the weight of the whole web; by referring to equation (4) for the strain on any point of a boom, it will be seen that the strain, and therefore the section area and weight, vary inversely as D; the absolute weight to be considered is therefore the difference of these two. Let w be the weight of the boom at any point, with a depth = D, then with a depth = D_1 the weight will equal $w_1 = w \times \frac{D}{D_1}$, similarly, if l be the length of a diagonal bar at a depth D, and w_2 the weight of its unit of length, and l_1 the length at depth D_1 and w_3 its total weight; then supposing them to have the same sectional area, $w_3 = w_2 \frac{\times l_1}{l}$ the maximum depth will be attained when the former weight exceeds the latter, or when

$$w \times \frac{D}{D_1} = \text{or} > w_2 \times \frac{l_1}{l}.$$

For the sake of simplicity the sectional areas of the diagonals before and after an increase to the depth of the girder have been considered equal, and so they would be for any moderate alteration in the value of D; if D however be very much increased, the diagonals would have to be made stronger, which might be accomplished either by augmenting this area or introducing an additional series of triangles, which would thus shorten the unsupported lengths of the bars, and so increase their strength. It will at once be perceived from this that a considerable addition may be made in the value of D, before the increased weight resulting from it counterbalances the diminution of strain on the booms arising from the same cause. As the depth of the girder becomes very great, there is another item which must be included as very considerably affecting the dead weight of the girder, and that is the large amount of material required for bracing in order to afford a sufficient degree of stiffness to the whole structure; in deep girders the extra metal used for this purpose is a very important consideration; this may be especially noticed in girders constructed from bad designs or on false principles, and in which the faults of bad construction are sought to be remedied by loading the girder with an immense amount of iron in the shape of bracing, which in many instances is more injurious than beneficial. In all large girders of the lattice form, and in fact of any other, except the tubular, whose booms

form their own bracing, a certain amount of bracing is necessary, which varies with the depth and the position of the moving load; the load on the bottom of the girder will generally be found to give a minimum, and when on the top a maximum; but with this part of the subject we are not at present concerned.

In designing girders, particularly those of the lattice form, care should be taken not to confound the two elements of stiffness and strength; the absolute strength of a girder may be accurately determined by pure theory; but it is only practice and experience which can correctly guide us in employing such forms of iron as will supply, along with the requisite strength, a very considerable amount also of rigidity. We should design, principally, with an eye to the strength of the structure, and add or modify according as may be necessary for the stiffness, or, what amounts to the same, we should design chiefly as if for a uniform load at rest, and then modify the design on the supposition that the load is movable and variable.

No portion of material in a girder acting solely the part of a stiffening piece, can be considered as an inherent portion of its absolute strength, it only adds to its strength insomuch as it prevents the calling into play of uncertain and varying forces (others than those provided for by theory), and which if not resisted would endanger the stability of the structure. It has been mentioned before that no mere stiffening iron can be included in the calculations respecting the strength of a girder, and it should be kept in mind that a girder may be very strong and yet very insecure; while again it may be very rigid and yet very weak.

We have now to consider the maximum strain which can be possibly brought upon the web under any conditions of loading, and which does not occur, as might at first be supposed, when the greatest weight is on the girder, that is when the girder is uniformly loaded, as is the case with the horizontal strains on the booms. This will be evident upon a little reflection respecting the double nature of the strains to which the diagonals are liable under the action of a uniformly distributed load. For, take the bar c in fig. 3; this bar is subject to a compressive strain from that portion of a uniform weight lying between it and the centre of the girder, and to a tensile strain from the portion resting between it and the abutment, and the actual strain upon it is the difference of these two, and which determines whether the bar is a strut or a tie. Or putting s_1, s_2 for these two different strains, we have for the whole strain $s = s_1 - s_2$; if we remove one of these strains we have $s = s_1$. This is what really takes place when a diagonal is under its maximum strain; let the bar c divide the girder into segments *a* and *b*, and let it be supposed to be loaded only over the larger segment, we thus remove one of the strains, and the bar c will be in a state of maximum compression. There will of course be a small tensile strain upon c due to the action of the dead weight of the girder between it and the abutment, but it will bear so small a proportion to the other that it is not necessary to take it into account. We will endeavor in our next to find a general expression for the value of this strain.

(To be Continued.)

Prevention of Decay in Timber for Shipbuilding and other Purposes.

From the Journal of the Society of Arts, No. 519.

(Continued from page 94.)

III.—*Precautions necessary to be taken in Erecting the Apparatus, either to neutralize the Agents of Decay, or to render the Timber impervious to their influence.*

A species of embalming was one of the oldest methods adopted. We are aware that from time immemorial either aromatics or poisons have been successfully employed in the preservation, for an almost indefinite period, of defunct organic bodies; and as animal substances and grasses, which otherwise decomposed with the greatest rapidity, are those whose tissues most readily admit preserving liquids, it is of course with them that the plans of preservation will best succeed. The effect of the poisonous solutions employed appears to be an insoluble combination of those solutions with the albumen of organic matters, by arresting their fermentation, which always precedes cryptogamic or fungoid vegetation, or the deposit of the eggs of xylophagous insects.

Dr. Boucherie's plans for preserving timber have some connexion with this method; and although he has not succeeded in their adaptation to the most valuable building timber, he will not the less have rendered an immense service to France, by substituting in lieu of oak (the scarcity of which is continually increasing) other kinds of timber suitable for many purposes, and especially for railways. In fact, experience has shown that timber is permeable, at least by aqueous solutions, only so long as the sap channels are free from incrustation. Such, in general, is the case with beech, elm, poplar, hornbeam, and the service tree, the capillary tubes of which are always open, or at least close very slowly. At the same time it may be said that there must remain even in these species some parts impervious to injection, while it is almost impossible but that a certain portion of the fibres will be more or less incrusted.

The sap woods, on the other hand, of every species, appear quite pervious; and on this quality is based the preparation of telegraphic poles, which, as every one knows, are made of young fir trees stripped of their bark, the inside of the fir, like that of most of the common resinous trees, being impermeable. But in all these cases these preparations are only to be applied to wood in the store or yard, or to that prepared but not put together.

The principal cause of the fermentation—always the forerunner of decay in timber—is the presence of an atmosphere of warm, damp, and stagnant air. On one of these three conditions being removed, the durability of timber would be immediately prolonged. Thus it is that we cannot contemplate without a feeling of admiration the woodwork of the oldest mansions or churches. The joists of the houses built by our ancestors last almost for ever, because they are in contact with air which is continually changing. Now, on the contrary, we foolishly enclose them between a ceiling of plaster (always very damp to begin with) and a floor; they rapidly decay, and sometimes

cause the most serious disasters, of which it is impossible to be forewarned. The timbers of our ships, placed as they are between the outside planking and the inside ceiling, are in the same predicament; the stagnant air of the channels is heated by the vicinity of the hold, and at the same time is charged with moisture, as much from the constant emission of aqueous vapor from the wood, as from the leakage of water through the seams, which, during rough weather, always open a little. Thus it is the timbers decay with frightful rapidity, endangering either the ship or the health of her crew.

The bolting ought to be considered as the only safeguard of a ship; for the planking, which enables her to float, only discharges that duty in proportion as it is solidly fastened to the ribs. But the grip of a bolt being proportionate to the friction that it experiences in the channel where it is driven, and that friction proportionable to the spring developed in the wood when the bolt is driven in, if the sides of the channel are altered, the adherence of the bolt is considerably lessened, the planks play one upon the other, eject the caulking, and allow water to penetrate through the seams. Under these circumstances the ship is no longer seaworthy, and must seek the nearest port to be repaired.

The signs of decay in timber are fungi. Some of them, now and then, are microscopic, and owe their existence to the sporules deposited on the surface; while fermentation, generated by prolonged contact with warm, damp, and stagnant air, is as a soil where seeds sow and nourish themselves. When a ship is under repair we are often astonished at the appearance of fungi, enormous in length or bulk, which are visible on all the surfaces of the circumference of the ribs in contact with the planks; and we may observe that the depth of the decay, from the outside to the inside, is in proportion to the size of the fungi. In general, however, they are not so abundant in the channels, or on the surface lengthways. This tends to show that the air in the fibrous tissue of the wood is not absolutely stagnant, the differences of the temperature of the several layers causing a slight current of rising and falling air. It is not the same even with the thin drafts of air enclosed on the surface in contact with the planking and the timbers; the friction that these drafts experience is sufficient to render their stagnation complete, it being a well-known fact that timber decays principally when in contact.

The causes and the development of decay in timber having been stated, the nature of the remedies, preventive or repressive, may be enumerated in the following order:—

1. By disturbing the stagnation of air in the channels or space and room of the timbers.
2. By getting rid of the confined air in contact with the timber.
3. By preparing the surface of timber in such a manner as to prevent the engendering and growth of fungi.
4. By impregnating the air in contact with the timber with a substance destructive to the sporules of the fungi.

It is a common error in building the hull of a ship to isolate the channels, and cut off their communication with the outer air—a bad practice, which must be abandoned. Formerly they were sparing of bull's eyes in the lower decks, but though the want of light added to the dirt of the hold, the advantage of them in caulking the seams was found too great to allow their use to be altogether discarded.

A very simple plan, and one without any inconvenience, to bring all the air channels into communication, would be, at equal distances on the surface of the length of the ribs, to bore holes about three centimetres ($1\frac{1}{8}$-inch) in diameter, which would not materially weaken the main timbers, equally taking care to arrange the half circular channeling on the lateral surface of the bends which keep apart the ribs. By these precautions, the air confined in the channels would be continually renewed; moreover, a quicker circulation in that air might be produced at any time by means of a small ventilator, similar to that used in mines, the handle of which would fit into one of the holes, all the others on the same side, one excepted, being shut. By these simple means the air channels would be rendered wholesome, and the fermentation on the surfaces of the length of the ribs be prevented; but they would not be sufficient to freshen the little drafts of air confined between the planking and the ceiling, which are retained by friction, so that it would be necessary to use some other means to get rid of them. They now exist only because, timber having but little compressibility, the surfaces in contact cannot mould themselves, which it is indispensable they should do, exactly one upon the other; but this can be accomplished by interposing an elastic substance, such as india rubber, either compressible like felt, or a cement like that of glaziers, but made with oil without driers, and mixed with a certain proportion of flour of sulphur. This last method the author thinks particularly worthy of trial.

But the most important plan is to prepare the surface of timber in such a way as to prevent fermentation, and to render the adherence and growth of fungi almost impossible. From time immemorial it has been the practice, particularly in the country, to burn the ends of poles driven into the ground, to preserve them from decay. According to the sage remark of the celebrated Carlomb, we should always take into serious consideration old and well known customs; but, in this instance, it is easy to admit the preserving effect of carbonization. In the first place, the surface of the timber is subjected to a considerable heat, the primary effect of which is to exhaust the sap of the epidermis, and to dry up the fermenting principles—here this is done by long exposure to the air: and in the second place, below the outside layer, completely carbonized, a scorched surface is found, that is to say, partly distilled and impregnated with the products of that distillation, which are creosoted and empyreumatic, the antiseptic properties of which are well known.

The author mentions instances of carbonized wood having been remarkably preserved for long periods under unfavorable circumstances, and observes that he was convinced by all these facts that the carbon-

ization of the timbers of ships would materially increase their durability; but that conviction was changed to certainty when he met with an article entitled "Seasoning of Timber," extracted from the "Architectural Navy," a work published in London in 1852. The writer having noticed the numerous methods tried in the beginning of the 18th century to increase the durability of timber for building purposes, adds, that "not long after this time the method of heating or charring timber, before it was worked up, and also that of stoving, that is, of heating it in kilns with sand, was practised in the royal dockyards. The *Royal William*, one of the most remarkable instances of durability that the British navy has supplied, was built either wholly or in part of timber that had been charred."

The author asks why has this excellent method not only not been persevered in, but even abandoned? This is owing to many causes; the difficulty and danger of the means adopted for charring, when either straw, fern, or shavings are made use of; the serious objections of burning the timber too deeply; or the incumbrance of the apparatus, and the length of the time occupied, if sand kilns sufficiently heated are used; and, finally, to indifference, or that system of routine against which the wisest plans so often contend in vain.

The methods of carbonization which the author first employed at Cherbourg, and which, by the order of the Minister of Marine, are about to be extended to all the dockyards of the French empire, are free from these objections, and realize, on the contrary, all the conditions to be desired, whether of simplicity, facility, safety, or economy. They are as follows:—

A gas-pipe is brought into the dockyard. An india rubber tube is screwed on, the other end of which, furnished with a joint, should be fixed at the side of the bench at which the men work. To this joint another end of a tube of sufficient length is fixed, and on that a little brass end is placed, similar to that of a fire-pump, but having inside a small pipe communicating with the reservoir of a foot bellows on the bench. The object of this bellows is, first, to mix with the gas the air necessary to obtain a complete combustion; and, in the second place, to impinge on the jet of flame such a force that it may be directed every way, and made to act not only on the surface of the wood, but in the holes, joints, bolts, mortices, &c., and in general on every part of the timber. The combustion takes place with the most perfect regularity, and, as can be proved, without the least danger, which, be it understood, does not exclude the precautions commonly prudent to adopt whenever fire is employed either on shipboard or in the dockyard.

The results obtained from experiments at the gasometer at Cherbourg, with the aid of a metre, and using a jet of average force, are—

1st. That the consumption of gas would be about 200 litres per square metre, or 200 gallons per 10 square feet of carbonized surface.

2d. That a workman, in an average day's work of 10 hours, would carbonize a surface of 40 square metres, or 440 square feet.

3d. That one workman is sufficient for a bellows supplying two jets of gas.

It may therefore be admitted that, at full work, the expense would not exceed 15 centimes (1½d.) a square metre, or 10 square feet. Besides, as has been ascertained by experiment, the operation can be facilitated by smearing, in the first instance, the surface of the timber with a little tar. By so doing these other advantages are gained—

1st. The carbonization of the cracks, that almost always occur on the surface of rough timber, is facilitated.

2d. It prevents the timber being affected too suddenly by the heat of the gas, which causes it to split.

3d. It prevents the cracking and splintering off of little ignited particles.

But beyond a mere facing of tar we must not go; a little thicker layer would impede, instead of furthering, the operation. Besides, we must stop as soon as the surface is freely carbonized, which shows that none of the parts below have escaped the charring—which is, I repeat, the end we seek. Under these circumstances, the depth carbonized will not exceed a third, or a fourth, of a millimetre. In shipbuilding, the carbonizing process ought to be applied to every surface in contact with, or, in general, intended to be surrounded by, moist and stagnant air.*

Moreover, it will be advantageously employed in the graving docks and slips, from the facility afforded in drying and hardening those parts of the hull intended to be preserved, and in destroying the fermentation which will be found there.

In house building, the process should be applied to the beams and joists embedded in the walls, or surrounded with plaster; to the joists of stables, cow-houses, wash-houses, &c.—which, although exposed to the free air, are constantly surrounded by a warm and moist atmosphere, an active cause of fermentation—to the wainscoting of ground floors; to the flooring beneath the parquet work, to the joints of tongues and rabbets, &c.; for carbonization by means of gas still leaves to the wood, for working purposes, all the sharpness of its edges.

By carbonization a practical and economical means is offered to railway companies of preserving, almost for ever, the sleepers, particularly oak, which cannot be impregnated by the injection of sulphate of copper. Let us suppose, for instance, that after, say 10 or 15 years, the sleepers on a line are taken up for the length of a mile, and replaced by new ones, the old when rasped and burnt again, will serve for the replacing of the following mile, and so on, one mile after the other.

With regard to vine-props and hop-poles, carbonization offers very great advantages in an economic point of view, by its cheap and practical method of operation.

As to the different methods of carbonization; when the timber-yard where the work is to be carried on is in the neighborhood of a gas

*Thus, as regards cased or cuirassed frigates, the external, as well as the internal surfaces of the planking, on which the iron plates are fixed, should be carbonized.

main, nothing can be easier than to lead it close to the work by a conducting tube, joining a little gasometer by which the issue is regulated.

If the expense of laying down the pipe is very heavy, compressed portable gas, like that distributed daily in Paris, as in many adjoining localities, can be used. The Imperial Marine adopt that plan, not only because their workshops are not lighted with gas, but, even if they had it, they prefer being able to carbonize certain parts of a vessel when afloat, for which it is sufficient to place on a boat or floating stage, moored alongside, a vessel charged with compressed gas; a regulator is put in communication with this, which allows the issue according to the pressure of the current of gas, or, in general, to such pressure as may be required.

In the place of coal gas, the cost of which is very great, carbonic oxide gas may be advantageously employed; for, while on the one hand, its illuminating power is very weak, its heating power, on the other, is very great.

Knowing the preservative effects of sulphur, the author was induced to try a species of plant, using flour of sulphur as a basis and linseed oil as an amalgamator.*

We know that when paint dries, to use a common expression, it is not by evaporation similar to that which water undergoes, but rather from the effect of a real combustion of the oil by the oxygen of the air, the result of which is a kind of solid resin, and it appeared to the author probable that the sulphur, having itself a great affinity for oxygen, would participate in that combustion from which would be generated sulphuric acid. These anticipations were fully realized. The planks painted for experiment emitted sulphurous vapors, and turned to red some strips of litmus paper previously moistened and subjected to the exhalations. Some logs of oak, painted in the same way, were buried in a dung-heap; six months afterwards the wood appeared perfectly intact, and exhaled a strong sulphurous odor, the action of which had, without doubt, prevented the formation of fungi.

It therefore appears proved that by smearing here and there either the surfaces of the length of the ribs or below the ceiling with this paint, a slightly sulphurous atmosphere will be developed in the hold, which will purify the air by destroying, at least in part, the sporules of the fungi.

This conclusion will be so much the more valuable, as it appears to be arrived at from the recent and curious experiments of M. Pastoreau, which, by depriving of air the sporules he had enclosed, annihilated their fermenting powers.

With regard to the carbonization of timber, it may be stated that, after having scraped the carbonized or charred layer, and pumiced the surface of the wood, it may be painted in the usual way, and with any color.

* The paint is composed of—

Flour of sulphur,	200 grammes,		3088 grains.
Common linseed oil,	135 "		2084 "
Prepared oil of manganese,	30 "		463 "

MECHANICS, PHYSICS, AND CHEMISTRY.

On the Ventilation, Warming, and Fire-proofing of Theatres.

From the Practical Mechanic's Journal, July, 1863.

In no other respect are our London theatres more defective, than in ventilation—in nothing so dangerous, as in the chance of an accident by fire. Contracted, narrow, tortuous, and mean as are the entrances and passages, (miscalled corridores,) and frightful as but too probably, would be the consequences, of such defective exits in the event of a rapidly spreading and serious accident of fire, yet are these evils comparatively forgotten and forgiven by the audience when once seated. But the evils of want of fresh air, and the smothering sensations of an irrespirable atmosphere—of oppressive heat in summer, and of cold and cold-giving drafts in our wet and raw winter nights, must be endured for the whole period of performance without mitigation, by the larger mass of the audience, whether penned into pit or gallery; nor with any variation, except that afforded by the sudden increase of stuffyness perceived the moment the drop scene falls between the acts, or the gradual intensification of the "choke damp," with the duration of the entertainment.

There are two or three curious varieties also, in the sensations of atmospherical discomfort that are to be found in our London houses. One of the very largest, is almost entirely ventilated (so far as ingress of fresh air goes) from the stage. The result is, that when the curtain is down, and towards the end of the evening, the sense of asphyxia is pressing, and as soon as the curtain is raised, a vast ocean of cold damp air, fragrant of musty canvas and defunct squib cases, rolls in over the pit from the stage, and produces a draft across the orchestra stalls that has often filled ourselves with wonder, as to how the fair-skinned and uncovered shoulders round us stood it; certainly such drafts are not borne with impunity to health by any one, and no small per centage of the consumptive diseases of the upper classes, we imagine, is traceable to the derangements of circulation and of lung, produced by like causes, operating in the great majority of our public places of resort. In another, and one of the most favorite of our theatres of the second magnitude, ventilation seems literally neglected, or provided for by no other perceptible method than that the house is full of air when the people come in, and they are welcome to make the most of it while they stay. In a third, and still smaller theatre, the *latrines* and urinals appear to be somewhere close to the pit, and the drains from these to be carried absolutely beneath the feet of the audience in that part of the house, which we have ourselves been obliged ere now to quit, with a sense of overpowering disgust.

Some very large promises were held out not many years ago as to improvements in ventilation and warmth, that were *intended* to be effected at one or more of our theatres, and such "good intentions" have been very widely and recently repeated in another quarter; but although we do not deny some little improvement, we fear there is

still but too much, to remind London play-goers of some of the characteristics of a place, said to be "paved with good intentions."

In all this, as in all that relates to the order, comfort, and grace of public assemblies, and especially those of public amusements, the French (and Germans even) are greatly in advance of us. There are several reasons for this as regards theatres, but they all, nearly, spring from this, that the problem of such buildings and of all their adjuncts and accessories, is *better thought out beforehand* than with us, and that the finger of administrative interference has this advantage at least, that it prevents the eagerness of irresponsible private speculation, thrusting theatres and other like buildings of assembly, into hemmed-in, crooked, and sordid sites, that from the outset, make proper accommodation impossible.

When, not long since, the Emperor determined to construct a new opera house, as one of the consequences of the Orsini attempt, (which, in a larger and more open front space would in practice have been impossible,) he created a mixed commission, to consider and decide upon the general conditions that should be viewed as common to, and be provided for, by all competing architectural designs. The treatment in this general form of the problem of opera-house construction, in the report of the commission, is a perfect model of lucidity and prevision.

Since that, a commission has been appointed in Paris, to report to the Prefect of the Seine upon the ventilation of theatres—the celebrated General Morin being the reporter to the commission. The report, like that on the opera-house, deals with the subject in a very wide and fundamental manner, and containing, as it does, the results not only of sound science, but the accumulated experience of the most theatrical city in the world, seems so important that we propose to place its main conclusions in brief before our readers.

The Commission on Ventilation was composed of MM. Dumas, Chaix d'est Ange, Pelouse, Rayer, Caristie, Gilbert, Balard, Grassi, and Morin, and their office was to examine and report upon the different projects presented for heating and ventilating the new theatres in process of construction at the "Place du Chatelet." The commission, in order to arrive at sound opinions, executed numerous trains of experiment.

They deal first with heating, and after having discussed from their own point of view the advantages and disadvantages of various systems of heating brought before them, they come to the conclusion that the "warm air calorifere" is the best, resting that opinion chiefly upon the fact that, after the assemblage of the audience, the function of any heating apparatus becomes of secondary importance in consequence of the heat developed by the spectators themselves, and by the gas lights or other illuminating means.

They then pass to the question of the volume of fresh air that is requisite to be supplied to ensure a sufficiently healthy and agreeable atmosphere, and arrive at the conclusion that thirty cubic metres per hour per spectator is necessary, and that this limit cannot be very largely exceeded, without entailing serious practical difficulties—such

as sensible drafts in the interior of the house, &c. They, however, express their full sense of the desirability of further increasing this volume, if it be found in practice possible.

This minimum supply, in English measure, amounts to 17·65 or nearly 18 cubic feet per minute per individual, and thus is almost *five times* as much as Tredgold (Treatise on Warming and Ventilation) considered sufficient. His measure was, however, greatly below what is necessary.

This large proportion for a theatre, holding 2000 people, would require a total area of admissive apertures equal to 600 square feet, for we may conclude that air entering through any aperture at a velocity beyond 12 inches per second, will give rise to sensible and disagreeable drafts, and probably even that velocity is too great. It is, in fact, to this difficult part of the problem of all ventilation, that the commission most fully addressed themselves. They admit that the mode proposed, and put in practice by the celebrated M. D'Arcet, one of the savans of the days of Napoleon the First, of bringing in the fresh air by a false bottom, or tube casings between the floors and ceilings of the boxes, is the most rational, but, in the cases before them, was inapplicable by the architectural conditions presented by the design of the two theatres already in progress of execution; and, on the other hand, they condemn D'Arcet's plan of taking off the vitiated and heated air at the lustre in the centre of the ceiling of the house, specifying, however, as objections, merely, that the latter are too well known to need repetition.

They caused a full-sized model of a tier of boxes to be constructed, and experimented with these as to the various methods proposed for admission and emission of air before coming to a conclusion.

They found that the introduction of either warm (tempered or untempered) fresh air at the bottom, i. e., floor level, of the boxes was inadmissible, as giving rise very generally to sensations of a disagreeable character.

They also found that, without any risk of inconvenience either by the ascent of hot or the pouring down of columns of cold air, they could introduce thin sheets of air of from 0·12 to 0·15 metres in thickness, by double casings formed between the ceilings and floors of the boxes.

They also consider that they have established that the evacuation or extraction of the vitiated air can be effected at the bottom and floor level of the boxes without any inconvenience whatever to the occupants.

The general result of their experiments is, in fact, that the vitiated air should be everywhere withdrawn at the floor levels. That it should be withdrawn as close as possible to the points at which it is rendered vitiated, and that the fresh air should be introduced at the nearest possible point to the place where it is needed, i. e., to where it is to be consumed by the spectators.

Besides these apertures for the introduction of fresh air at the ceilings of the boxes, they find that it is indispensable to add to them a

zone of thin apertures all round the (*Rampe*) balustrade of the tiers of boxes, and on the proscenium, an annulus all round the sides and overhead, (as we understand their expression,) but so proportioned as not to annoy the actors by descending currents.

They also provide apertures in the walls separating the stage area from the audience part of the house.

To ensure the entrance of fresh air by *all* these apertures, they have not deemed it necessary to resort to any mechanical methods of exhaustion or pumping. They propose very ingeniously to make use of the ascentional power inherent in the heating apparatus of the colorifere, as the main agent to effect this. In fact, they propose to so construct the furnace, &c., of the colorifere, that after it has warmed the house, and while the audience are arriving, and the house getting filled, the hot air, &c., from it, shall no longer be discharged into the house, but into an air shaft, and that into this, with a current of ascent already produced, all the out draft flues should be put into communication.

Of course, this report does not deal with minute details, that may be easily inferred, as to *modes* of doing this, and constructive arrangements for increasing or reducing the amount of ventilation, more or less suddenly, during the progress of the performance.

In addition to this, however, they propose that the heat of the central lustre shall, by a surmounting flue of narrow area, be made the means of clearing off the products of its own combustion, and, as an auxiliary, a *certain portion* of the heated air that must fly up to the ceiling of the central area of the house. They add again to this, special gas jets in certain of the outcast air flues in the walls of the building. They also propose to utilize in this way the heat, and at the same time get rid of the products of combustion of the lights at the front of the stage. They propose to effect this, in ways that tend to free the actors from much of the danger and inconvenience that they have hitherto been exposed to—by the flame, the glare, heat, and drafts produced by the common foot-lights; and they recommend that, by the arrangement of suitable reflectors, such as have been already employed with great success at the new Opera Français, the total amount of gas necessary to be consumed to illuminate the stage, be reduced. The wisdom of this is obvious—every needless gas light that can be got rid of is equivalent to clearing the house of the noxious respirations of three or four spectators.

The final issue of this report has been the stoppage of two plans for the heating and ventilation of the Theatre Lyrique, and Theatre du Cirque, which had been already in hand with the sanction of the Prefect of the Seine.

The plans of the commissioners have been sanctioned and placed in course of execution at the former theatre, but, as respects the latter, pre-existent architectural conditions were found to involve so serious an expense, that the plans of the commission were not adopted with respect to it, and their report is silent as to the details of the project actually in course of execution, and not emanating from them.

There is, perhaps, nothing of actual novelty in any one of the propositions of this report. The combination of arrangements proposed is one, however, that seems extremely well thought out, and likely to be in practice quite successful. So far as the notion of taking off by distinct means, and preserving the air of the body of the house from the contamination of the products of combustion of gas lights, &c., it is but carrying out what was done some years ago with success at our own houses of Parliament by the use of the patent burners of Faraday —the philosophical value of which is said to have been suggested by one who has conferred unfading lustre upon that name. The injudiciousness of admitting either fresh, cold, or warmed air under the feet of the audience, has also been fully *constaté* in England for several years; and the advisability of admitting it at mid levels, (above 7 to 10 feet from the floor,) and taking off foul air both at the floor and at the ceiling, has been advocated and practised by some few of the best of our own practitioners of ventilation and heating; but all these methods have not been combined that we are aware of, and certainly not applied to any British theatre. It may be remarked, however, that this report unequivocally condemns the plan which is still in actual use, in the ventilation, &c., of our House of Commons, namely, the bringing in the fresh air through apertures in the floor, and through those of the carpeting with which the latter is covered; and we are ourselves, after some experience in this special branch of engineering, (if it be dignified with that name,) satisfied that their condemnation is just. Let the air to be admitted, be ever so well *washed* and purified, it becomes filled with particles of dust, and wool flock, and flue, as it passes up through a carpet over which the soles of shoes are continually passing. The air, if *cooler* than that of the room, as is in summer the case with the House of Commons, by as much as 10° to 15°, soon begins to make the feet and legs of those sitting feel cold and chilled; if it be *warmer*, it rises up along the body in insensible streams, which yet make themselves known after a time, by producing those rheumatic pains that are well known to follow the passage of currents of air of different temperatures, though the cause of their effect is, as yet unknown. In either case, the circulation in the lower limbs, and especially of old people, is deranged by cold on the one side, or by congestion due to local warmth on the other, and hence uneasy sensations, and those fidgetty feelings, that are the inarticulate and ill-understood, but not the less the real cause. of the frequent complaints made by members as to the state of the warming and ventilation of the house—and some of which were repeated only this week.

No building of whatever class more imperatively demands to be constructed *really fire-proof* than a theatre. We say *really*, because sham fire-proofing, enough to base an advertisement upon, and scarcely that with truth is not unknown. If a theatre, however, is to be fire-proof in such a sense as to be of any use in saving the lives of a densely crowded audience, suddenly alarmed by an outbreak of fire, which, of all other places in the house, is most likely to originate behind the

scenes, or in some of the numerous adjuncts of the stage, it must be so constructed that, for something like an hour, or one-half of it at the least, the audience part of the house must not only be free from conflagration itself, but must remain free enough from smoke, that the escaping spectators shall be able to see their way, and shall not become suffocated in corridors and staircases filled with the products of combustion, and with the lights all extinguished. To this end, it is indispensable that, at the first moment of serious alarm, a flexible iron curtain, made of hoop-iron, generally on the plan of Bunnett and Corpe's fire-proof revolving shutters, but lighter, should be provided, above the proscenium and on the stage side of the curtain, and be capable of being dropped at a moment's notice. This need not be of necessity, really fire-proof, though best if it were so, but it must cut off the main volume of heat and smoke of a burning stage from the audience part of the house, and be capable of resisting the passage of flame through it for an hour at least.

As for the rest, in building a new theatre, we are satisfied that no cheaper plan of constructing the floors of the several tiers of boxes could, in the present state of plate iron work manufacture, be adopted, than to make them all consist of hollow box cantelevers, sustained by the surrounding walls, and free from all supports, or view-obscuring props, in front. Such hollow iron work would give the utmost facility for the safe introduction of fresh, and the taking off of vitiated air, where desired.

The floors of the corridors behind should, in like manner, consist of hollow lamina of plate iron, giving room in the simplest manner to the conduting of the air flues, away and towards each tier of boxes.

The stair-cases should be of stone or iron, and at each story should be in communication with the outdraft and indraft of the flues. All should converge to two insulated towers one at either side of the house, placed as near to the thorough wall of separation between stage and audience as possible, and within which all the heating and ventilating apparatus proper should be localized.

The roof over the audience should be wholly of iron, and the *plafond* of the ceiling, painted directly upon a surface of sheet iron, riveted to the frame, and no carpenters shop, nor store room for scenery or properties, should be permitted within its hollow space, which should be divided by several sheet iron *septa* into distinct spaces of moderate area, each communicating by iron doors; means should exist for closing, by an iron cover, the outdraft flue over the central lustre. With such provisions made, not in bits and scraps of temporary makeshift, but *ab initio*, and as parts of a systematic plan, a theatre *could* scarcely be burnt at the audience side of the curtain. Iron hollow floors to the boxes and galleries, &c., would, by their powerful *resonance*, greatly contribute to the fine effect of musical performance; and as regards the noise that may be apprehended by the trampling of feet along the corridors, and in entering and leaving the boxes or places of the spectators, it is readily guarded against, by laying a thick coating of kamptulicon, or other like sort of matting all over the floors.

Fire proofing *might* also be extended to the scenic department of a theatre, but, here, from the vast mass of combustible matter usually *kept* upon the stage, in the shape of scenery and a thousand odds and ends, the fire proofing, to be *real*, would have to assume the same proportions necessary for a first-class fire-proof warehouse. It is *possible* to make the stage so, that like a great furnace, it should be capable of remaining practically uninjured as to its shell, after its combustible contents had been quite burnt out to ashes within it—but to effect this the expenditure must be proportionably large, and it is not worth while incurring this large cost. The proper method is that adopted at the Opernhaus at Berlin, and, indeed, at many of the great, German, and other Continental theatres. Let the stage be encumbered only with the scenery actually in use for the week. Do not make it also a lumber room and constant store for scenery not in use. Provide a separate building, and at a little distance, on the ground level, both for the preparation and the storage of scenery, &c., and so limit to the *minimum* amount, the quantity of burnable material on the stage.

The stage itself should, in every case, possess a ceiling of sheet iron beneath its joists and boarding, every where but at the traps, and the under side of these should be nailed over with sheet iron.

The ingenious Earl of Stanhope, and long after him, the late Mr. Jesse Hartley, C. E., of Liverpool, proved, conclusively the immense *delay* in the progress of combustion, conferred by this simple and inexpensive means, upon any wooden floor. The supply of air to support the fire is, in fact, cut nearly off at the lower or effective side.

EDITOR.

International Exhibition, 1862.—*Jurors' Report.*

From the Lond. Civ. Eng. and Arch. Jour., Nov., 1862.

CLASS VIII.—MACHINERY IN GENERAL. *Subdivision I. Prime Movers.*

(Continued from page 99.)

SECTION III.—*Marine Steam Engines.*—The general remarks as to progress since 1851, which have been made in Section II., as to land engines, are applicable to marine engines also. The improvements in workmanship are even more striking.

A very large number of marine engines exhibited possess merit of a high order, as this Jury have testified by their awards. They have also indicated briefly in the reasons given for the awards, the particular kind of merit by which each engine is most distinguished.

Of the marine steam engines, by far the greater number are horizontal screw engines; the reason probably being that such is the arrangement best suited for ships of war, and that the engines of ships of war can more easily be spared for purposes of exhibition than those of merchant ships.

The horizontal engines are numbered as follows:—United Kingdom, 1891, 1902, 1926, 1955, 1964, 2632 (model), 1897, 1962 (model); France, 1132, 1195; Sweden, 274. In this form of engine the space is more limited than in any other, and difficulties are thus caused

which the skill of the engineer is exerted to overcome in various ways. Hence arise great varieties in the details of the designs of horizontal engines. For example, the engines of Humphrys and Tennant (United Kingdom—1891) are marked by simplicity and accessibility; the action is direct, the stroke and connecting-rod short, and the cylinder of large diameter. In other examples a longer stroke and connecting-rod are obtained in various ways: in those of Maudslay, Sons, and Field, (United Kingdom—1926), Ravenhill, Salkeld, and Co. (United Kingdom—1962), Nouvelle Société des Forges et Chantiers (France 1195), A. W. Frestadius (Sweden—274), and others, by double piston rods; in that of E. Nillus (France—1132), by double piston-rods, connected with trunks in the air-pump, a construction which is also used in Britain; in that of G. Rennie and Sons (United Kingdom—1964), by trunks in the cylinders: in that of J. Penn and Sons (United Kingdom—1955), by trunks passing completely through the cylinders, &c.

A peculiar arrangement of a duplex horizontal trunk-engine, in which the inside of the trunk is made available as cylinder space by the aid of a fixed piston, is represented by a model in the British division of the Western Annexe, which is not mentioned in the Catalogue. (Exhibited by Mr. E. E. Allen.) The engine of M. Frestadius (Sweden—274) has concentric double cylinders.

Amongst oblique screw engines may be mentioned those shown in the drawings of Armengaud (France—1181), and of Randolph, Elder, and Co. (United Kingdom—1960), the latter of which arrived too late to be adjudicated upon.

As examples of the vertical inverted-cylinder screw engine, so well suited for merchant ships, the engines of Morrison and Co. (United Kingdom—1936), Tod and M'Gregor (United Kingdom—2009), and Richardson and Sons (United Kingdom—1965) may be noticed, as well as a model exhibited by Humphrys and Tennant (United Kingdom—1891), which will be again mentioned further on. The first three of these have surface condensers, the first two with horizontal, and the third with vertical tubes. The first two are very compact and convenient in their arrangement; the third may be regarded either as a working model or a pair of small engines. The steam before entering the surface condenser, gives out much of its heat to the feed-water, which traverses a set of tubes surrounded by the exhaust steam.

The engines of Maudslay and Co. are accompanied by a very complete and well-executed set of moving models of marine engines, of a great variety of kinds, both paddle and screw.

The engines of Humphrys and Tennant are accompanied by moving models of themselves, and also of a pair of vertical screw engines, noted for their efficiency and economy in practice, being those of the Mooltan, these are double-cylindered expansive engines, each small cylinder being directly on the top of its large cylinder.

Paddle engines are represented by working models exhibited by Maudslay, Sons, and Field (United Kingdom—1926); J. Penn and Sons (United Kingdom—1955), and Ravenhill, Salkeld and Co. (Uni-

ted Kingdom—1962); and by the drawing of Messrs. R. Napier and Sons (United Kingdom—1939). The model of Messrs. Ravenhill has feathering paddles and oblique cylinders; while that of Messrs. Penn has oscillating cylinders. The only pair of full-sized paddle engines are exhibited by Messrs. Escher, Wyss and Co. (Switzerland—104).

The valve gear and expansion gear of the marine engines are very various. For reversing, the link motion is used in almost every case: an exception is found in the engine of the Mediterranean Company, above referred to (France—1195), where the engine is reversed by a piece of wheel-work, which when acted upon by hand causes each eccentric to reverse its position on the shaft that carries it. In Humphrys and Tennant's engines an improvement in the construction of the link has been carried out, by making it of a single bar embraced by a slider, instead of a pair of bars with a slider between them.

In some examples, the link motion is used for expansive working; but in most, the cut-off is effected by means of a separate expansion valve, the mechanism for working which presents a great variety of designs.

Amongst various peculiarities of arrangement, may be noted that of the pair of horizontal screw engines of Messrs. Rennie, in which the cylinders are at opposite sides of the shaft; each cylinder is directly opposite the air-pump of the other; and each cylinder exhausts directly into the condenser by its side, so that exhaust-pipes bridging over the shaft are dispensed with.

The horizontal trunk marine screw engines of Messrs. Penn being exhibited by a member of this Jury, could not be made the subject of an award. They are accompanied by a model already referred to, and by separate parts of engines, showing great perfection of material and workmanship.

SECTION IV.—*Windmills.*—The windmill of Wentworth and Jarvis (United States—54) is chiefly remarkable for its regulator, which consists of a pair of slightly diverging vanes, forming a sort of tail behind the cap of the windmill, and so connected with the sail, that when the vanes, by the increased impulse of the wind, are pressed closer together, the sails are turned into a position that exposes less surface to the wind.

SECTION V.—*Water-wheels and Turbines.*—The conditions to be fulfilled in order that the efficiency of a turbine, or water-wheel of any other kind, may be the greatest possible, are that the water shall begin to act on the wheel without shock, and shall leave it with no more velocity than is necessary in order to prevent the wheel from being choked with back water. All the turbines to which honors have been awarded by this Jury, are capable of fulfilling those conditions when properly managed.

Turbines have been classed according to the general direction of the flow by which the water is carried through the wheel, independently of the whirling motion which is first impressed on the water by the guide blades, and afterwards taken away during the action of the wa-

ter on the wheel. According to this mode of classification those of the North Moor Foundry Company (Schiele's) (United Kingdom—1948) and of Fontaine and Brault (France—1173) are "parallel-flow" turbines, because the general flow of the water is parallel to the axis; and that of Williamson Brothers (Thomson's) (United Kingdom—2026), is an "inward-flow" turbine, because the general flow is towards the axis. In order that the conditions of greatest efficiency may be fulfilled with different loads, the mode of varying the quantity of water supplied ought to be such as to change as little as possible the speed of the whirling component of its motion. This is effected in parallel-flow turbines by supplying the water through a ring of orifices, a greater or less number of which are completely closed when the supply is to be varied, so that all the orifices which are open are fully open. In the inward-flow turbine or "vortex wheel," the same object is obtained by varying the obliquity of the guide-blades.

The drawing of M. Sagebien (France—1154) represents a water-wheel which on theoretical grounds may be considered advantageous for low falls; but the Jury had not, during their proceedings, sufficient data to enable them to make an award upon it.

Section VI.—*Water Pressure Engines.*—The water-pressure engines of Sir W. G. Armstrong and Co. (United Kingdom—1785) are capable of working and standing still at intervals without waste of power or of water. This (in the absence of a reservoir) is effected by the aid of the "accumulator," being a cylinder like that of a hydraulic press, having a plunger loaded according to the pressure to be maintained, and being large enough to contain the store of water which collects when the machinery is at rest, and to supply the surplus of water required when the machinery is moving. One of the engines consists chiefly of a cylinder and piston of long stroke for working a hydraulic crane through pulleys and chain-tackle; another is an engine for producing rotary motion at high speeds, with three oscillating cylinders, having plungers which act upon three cranks, making angles of 120° with each other. This engine is characterized by the use of "relief clacks;" those are valves which upon the occurrence of any tendency to excessive increase or diminution of pressure in the cylinder, permit water to flow back from the cylinder into the supply pipe, or from the discharge-pipe into the cylinder, as the case may be, and thus prevent shocks without wasting water.

Carrett, Marshall and Co. (United Kingdom—1813) exhibit a double-acting water-pressure engine specially adapted to the blowing of organs, in which the piston moves with a uniform speed and there is no fly-wheel.

The water-wheel exhibited by Mr. E. O. Richard (Canada—119) is really a kind of rotary water-pressure engine.

Section VII.—*Vacuum-power Engine.*—The Jury could find no engines to which the above description seemed to be applicable.

Section VIII.—*Electro-Magnetic Motive Power Engines.*—Some engines of this kind were exhibited, in which much ingenuity was dis-

played; but inasmuch as the Jury had no opportunity of ascertaining the convenience and efficiency of those machines while working, either by inspection or from the information of others, they did not conceive themselves warranted in making any award upon them. It is well known that certain electro-magnetic engines are at present in extensive practical use for driving small machinery in which the cost of motive power is unimportant; but no specimen of those engines was exhibited. The electro-magnetic engine of D. M'Callum (United Kingdom—1916) was carefully searched for, but not found.

SECTION IX.—*Miscellaneous Prime Movers.*—The gas engines of C. W. Siemens (United Kingdom—1987), and Lenoir and Co. (France—1188) are driven by the combustion of a mixture of coal gas and air so proportioned as not to be dangerously explosive; the mixture is fired at each stroke by an electric spark. From the report of M. Tresca on Lenoir's engine, it appears that this engine is not economical of fuel as compared with a steam engine, but that it is very convenient and useful for driving machinery in situations where a steam engine cannot be employed. Siemens' engine is provided with a regenerator for saving a great part of the heat which would otherwise be discharged with the waste gases; and there are theoretical grounds for expecting it to be economical; but precise experimental and practical data as to its economy and efficiency do not yet exist.

The engine of E. B. Neill (United Kingdom—1943), and an engine of the United States without a number, are both hot air engines of a kind invented by Captain Ericsson. Those exhibited by C. H. Dennison (United States—82), and that of Schwarzkopf (Prussia—1319), are also hot air engines. No advantage in point of economy over the steam engine is claimed for any of these, their proper use being, like that of the electro-magnetic engine and the gas engine, to furnish a convenient motive power for small machines where a steam engine cannot be employed. As the working of these engines within the Exhibition building would have been inconsistent with the regulation which prohibits the lighting of fires in it, the Jury, in order to satisfy themselves that the engines worked in a smooth, steady, and manageable way, obtained from Her Majesty's Commissioners permission for the exhibitors to remove them for a time from the building, and set them to work outside. The results were satisfactory in the case of the two American engines; but the Prussian engine was unfortunately prevented, by accidental circumstances, from being set to work until after the proceedings of the Jury were closed, so that they could not make any award upon it. It was afterwards, however, set to work in the boiler yard; when it moved smoothly and steadily, and was easily started and stopped. Both the American engines take in at each stroke a fresh supply of air, which is afterwards discharged; Schwarzkopf's engine retains the same air permanently, and transfers it back and forward between the hot and cold end of a receiver alternately.

W. J. MACQUORN RANKINE, *Reporter.*

(To be Continued.)

For the Journal of the Franklin Institute.

Steam Boilers in New York.

The importance of an efficient inspection of the condition and management of steam boilers in this city are manifest, from the fact that a great many are located in crowded buildings, and beneath sidewalks. This could not be satisfactorily ascertained under the old law, but under the new, demanding that each engineer shall be examined as to his competence to take charge of his boiler or boilers, it is assumed that he understands its condition and essential appurtenances, and if, in relation thereto, he cannot pass a satisfactory examination, he is suspended from duty and "held over" until he is able to do so. Hence, from the examination of each engineer and the inspection of each boiler by the Inspectors, the Department obtains the requisite information to enable it to enforce the provisions of the law. Capt. B. G. Lord, of the Sanitary Company of New York, in his second annual report, just rendered, relative to this matter, says:—

"But one explosion has occurred since the new law has been in force, and this arose from no neglect of the Department, or defect of the boiler, which had been properly examined, but through flagrant mismanagement and carelessness. The person in charge had neither received, nor been examined for a certificate as engineer."

The following table shows the amount of work performed by the Inspector of this Department during the past year:—

Number of boilers examined,	2987
" " tested hydrostatically,	671
" " condemned and removed,	10
" " found defective, and repaired,	159
" gauges " " "	132
" " cocks " "	226
" safety-valves " "	95
Total number of defects remedied,	622

B.

New York, May 7, 1863.

Red Lead Coating of Iron Ships.

From the London Practical Mechanic's Journal, July, 1863.

M. Jouvin, in two letters addressed to M. Dumas in *Comptes Rendu*, Tome 51, p. 529-980, has recorded some interesting and highly important observations upon the effect of sea water and air upon iron ships, coated below the water-line with red lead oil paint, mixed with 7½ per cent. of pure sulphate of mercury. Two ships, the *Guinne* and the *Bearne*, after having been at sea for about a year, and made a tropical voyage, were found, upon being docked, covered below the water-line with small pustules or blisters of the coating, which all contained solutions of chloride of iron, chloride of lead, and metallic lead in crystals. The latter had been reduced at the expense of the cor-

rosion of the iron of the ship; all trace of the sulphate of mercury had disappeared. Thus these results, supported as they are by careful analyses of the matter found in the blisters, upon both ships, prove that in place of being a preservative to iron ships, red lead coating is a decidedly destructive agent in contact with their hulls below the water-line.

Johnson's Deep Sea Pressure-Gauge.

From the London Civ. Eng. and Arch. Jour., Sept., 1862.

Mr. Henry Johnson shows (2920)* his Deep Sea Pressure-Gauge. It is well known that in deep sea soundings the pressure of water is too great to admit of accurate measurement by the compression of any highly elastic fluid confined in a small portable instrument. For a long period water was considered incompressible, but it has been found to possess a slight degree of elasticity, sufficient to render its compression in a vessel available as an indication of the compression or density of the water into which it is lowered. In the year 1762, Dec. 16th, Mr. Canton communicated to the Royal Society the results of his experiments on the compressibility of water—"Philosophical Transactions," vol. lii. p. 640. He took a small glass tube of about 2 feet in length, with a ball at one end of it of $1\frac{1}{4}$ inches in diameter, and filled the ball and part of the tube with water exhausted of air, and left the tube open, that the ball, whether in rarefied or condensed air, might always be equally pressed within and without. He placed the ball and tube under the receiver of an air-pump, and could see the degree of expansion of the water answering to any degree of the rarefaction of the air; and also placed the ball and tube into the glass receiver of a condensing engine, in which he could see the degree of compression answering to any degree of condensation of the air. In this way he found by repeated trials, when the temperature was about 50° Fahr., and the barometer about a mean height, that the water expanded and rose in the tube, by removing the weight of the atmosphere, one part in 21,740, and that it was as much compressed under the weight of an additional atmosphere. More recently, Mr. Perkins found, when subjecting water to great pressure, a diminution in volume of $\frac{6}{100}$th parts under a pressure of 1120 atmospheres, equal to one part in 18,666 per atmosphere. The experiments of Mr. Perkins, exhibited at the Adelaide Gallery, appeared to be intended as a demonstration of the fact of progressive compression, rather than a basis for minute calculation.

The effect of pressure of water at great depths is illustrated by a very interesting experiment made by Rear Admiral Sir James Clarke Ross, who, after lowering several bottles which returned to the surface with the corks reversed, lowered a bottle fitted with a tube; a cork being suspended in the bottle so as to enter the tube in the event of the water in the bottle being condensed under heavy pressure, and expanding upon the raising of the bottle and the diminution of the

* At the National Exhibition.

pressure. Upon the return of the bottle to the surface, it was found that the cork had been forced some distance along the tube, and the compression of the water in the bottle, and its subsequent expansion, were thus demonstrated.

In experiments conducted with a pressure-gauge made of metal, it was found that air-bubbles adhered to the inner surface of the pressure-gauge, and materially affected the results. This difficulty is avoided in the instrument now exhibited, which is composed of glass, so that the absence of air-bubbles may be ascertained by inspection before any experiment is made. The instrument consists of a cylindrical glass vessel with a long neck or stem finely graduated; within which are placed a flat elastic ring to act as an index, and an elastic stopper.

When used, the pressure-gauge should be well rinsed with warm water, to prevent the adhesion of air to its inner surface, and then filled to the top of the stem with sea-water boiled to free it from air. In the event of this water being poured in while warm, it will be necessary to fill up the stem after the water has cooled down to the temperature of the atmosphere, so that the stopper may be inserted without confining any air beneath it. A small vent or grooved needle, affording a passage for the escape of superfluous water, should be pushed in with the stopper, which should be slightly lubricated to prevent excessive friction, until the lower end of the stopper is coincident with the zero or top line of the graduated scale, marked 2000, when it will also touch the flat elastic ring. The vent should then be withdrawn, and the stem will be tightly closed by the stopper. When lowered into water of greater density, the water in the pressure-gauge is compressed by external pressure until of equal density with the surrounding water, and the elastic stopper and the elastic ring are pressed along the tube towards the cylinder. When raised, as the external pressure diminishes, the water in the pressure-gauge expands, and gradually presses back the elastic stopper, the elastic ring remaining as an index to mark the extreme compression. When the water attains the temperature of the atmosphere, the stopper will have returned to its original position, less a small difference arising from friction.

The volume of water in the cylinder and stem is considered as consisting of 2000 parts, of which the cylinder contains nine-tenths, or 1800 parts or degrees, and the stem one-tenth or 200 degrees, and which are numbered 1801 to 2000. The graduated scale on the stem may easily be read to one-tenth of a degree, or $\frac{1}{20000}$th part of the whole volume of water. For the compression of one part in 20,000 of boiled sea-water, a pressure is required of 15·8 lbs. avoirdupois per square inch, equal to the pressure of a depth of 35·446 feet, or nearly six fathoms. This amount of pressure, which is the result of several experiments, and which is confirmed by the observations of Mr. Canton, appears to be a fair basis for the compilation of tables of comparison of depth and pressure.

The instruments should, however, be attached to sounding lines, and

the indications compared with the depths shown by the lead. The results would form a table of comparison of depth and pressure of practical use in determining depths when strong currents render the use of the lead uncertain. A correction will be required for the variation in volume of water with change of temperature, and which is not uniform, being greater at high temperatures, as for instance—

At 86° the volume is for this object estimated at	20,000 parts.
At 65° the volume is contracted to .	19,932·5 "
The difference for 21° being . .	67·5 parts.
or for 1 degree 3·21 parts.	
The volume at 65° of . . .	19,932·5 parts.
is contracted at 31° to . . .	19,880 "
The difference being for 34° . .	52·5 parts.
or for 1 degree 1·55.	

TABLE showing the variation in the volume of sea-water, boiled to free it from air, with change of temperature. Thermometer 67·5° Fahr. Barometer 29·92. The volume at 80° being considered as unity, and divided into 20,000 parts. A gentle motion kept up to equalize the temperature of the sea-water has prevented its freezing at 28·5°.

Deg. Fah.	No. of Parts.	Deg. Fah.	No. of Parts.
86°	20000·0	53°	19905·0
85	19996·0	52	19903·0
84	19992·5	51	19901·0
83	19989·0	50	19899·0
82	19985·5	49	19897·0
81	19982·0	48	19895·0
80	19978·5	47	19894·0
79	19975·0	46	19892·5
78	19971·5	45	19891·0
77	19968·0	44	19890·0
76	19964·7	43	19889·0
75	19961·5	42	19888·0
74	19958·25	41	19886·7
73	19955·0	40	19885·5
72	19951·5	39	16884·5
71	19948·0	38	19883·5
70	19945·0	37	19883·0
69	19942·5	36	19882·5
68	19940·0	35	19882·0
67	19937·5	34	19881·5
66	19935·0	33	19881·0
65	19932·5	32	19880·5
64	19930·0	31	19880·0
63	19927·5	30	19880·0
62	19925·0	29	19880·0
61	19922·5	28	19880·0
60	19920·0	27	19880·0
59	19917·5	26	19880·0
58	19915·0	25	19880·0
57	19913·0	24	19880·0
56	19911·0	23	19880·0
55	19909·0	22	19880·0
54	19907·0		

On the Change of Form assumed by Wrought Iron and other Metals when Heated and then Cooled by Partial Immersion in water. By Lieut. Col. H. Clerk, R. A., F. R. S.

From the Lond. Proceedings of the Royal Society, March, 1863.

Origin of the Experiments.—A short time ago, when about to shoe a wheel with a hoop-tire, to which it was necessary to give a bevel of about $\frac{3}{8}$ths of an inch, one of the workmen employed suggested that the bevel could be given by heating the tire red-hot and then immersing it one-half its depth in cold water. This was tried, and found to answer perfectly, that portion of the tire which was out of the water being reduced in diameter. The tire was 3 inches wide, $\frac{1}{2}$ inch thick, and 4′ 2″ in diameter.

As this result was curious and not generally known, I considered it desirable to institute some further experiments in order to try how far, by successive heatings and coolings, this change of form could be augmented, and also whether the same effect could be produced on other metals than wrought iron.

Mode of Carrying out the Experiments.—The experiments were made on cylinders of wrought iron of different dimensions, both hollow and solid; immersed, some to one-half of their depth, others to two-thirds; also on similar cylinders of cast iron, steel, zinc, tin, and gun-metal.

The specimens experimented on were all accurately turned in a lathe to the required dimensions, which were carefully noted; they were then heated to a red heat in a wood-furnace used for heating the tires of wheels. As soon as they had acquired the proper heat, they were taken out and immersed in water to one-half or two-thirds of their depth (as stated in the experiment). The temperature of the water ranged from 60° to 70° Fahr.

The specimens were allowed to remain in the water about two minutes, in which time the portion in the air had lost all redness, and that in the water had become sufficiently cool to handle. These alternate heatings and coolings were repeated till the metal showed signs of cracking and giving way.

The dimensions were noted after every five heatings. The circumferences were measured in preference to the diameters, as the true circular form was liable to alter.

General Results.—It will be seen by an inspection of the figures that the general effect is a maximum contraction of the metal about one inch above the water-line; and that this is the same whether the metal be immersed one-half or two-thirds of its depth, or whether it be nine, six, or three inches deep. With wrought iron the heatings and coolings could be repeated from fifteen to twenty times before the metal showed any signs of separation; but with cast iron after the fifth heating the metal was cracked, and the hollow cylinder separated all round just below the water-line after the second heating. Cast steel stood twenty heatings, but was very much cracked all over its surface. As respects the change of form of cast iron and steel, the

result was similar to that in wrought iron, but not nearly so large in amount. The cast iron did not return to its original dimensions, but the smallest diameter was about one inch above the water-line.

Tin showed no change of form, there being apparently no intermediate state between the melting-point and absolute solidity. Brass, gun-metal, and zinc showed the effect slightly; but instead of a contraction just above the water-line, there was an expansion or bulging.

The effect on wrought iron is best seen in the solid cylinder (figs. 9 and 10), where the displacement of particles just above the water-line appears to be compensated by the bulgings at the two extremities.

The specimens of wrought iron were submitted by Mr. Abel (Chemist to the War Department) to chemical analysis, and he informs me that he found nothing noteworthy in the composition of the metal; nor was there any appreciable difference in the specific gravity of the metal taken from different parts of the specimen. It appears therefore to be simply a movement of the particles whilst the metal is in a soft or semifluid state.

The following is an account of the experiments, which were carried out under the superintendence of Mr. Butter, Draughtsman of the Royal Carriage Department, to whom also I am indebted for the accompanying diagrams. The exact dimensions of each specimen before and after heating are given in a tabulated form at the end of the paper, to facilitate comparsion.

In figs. 22 and 23 the changes in form of 9″ cylinders (one immersed one-half, the other two-thirds its depth) are shown in section after every five heatings (half the full size).

Experiment 1.—A 4 ft. 2 in. hoop-tire of 3 inches breadth and $\frac{3}{8}$ths inch in thickness (fig. 1) was heated and cooled by being immersed to half its depth in cold water five times, by which the effect shown in fig. 2 was produced.

FIG. 1.

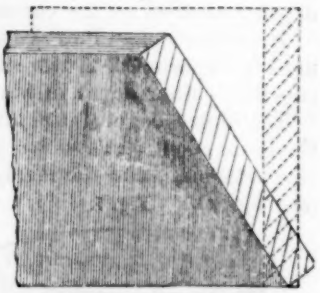
One-eighteenth of full size.

FIG. 2.

The upper edge, or that cooled in air, had contracted 8 ins., or $\frac{1}{20}$th

its entire length, and slightly increased in thickness; while the lower edge, cooled in water, had expanded ·875 inch, making a difference between the two circumferences of 8·875 inches. The breadth remained unaltered (3 ins), and kept perfectly straight.

Fig. 3.



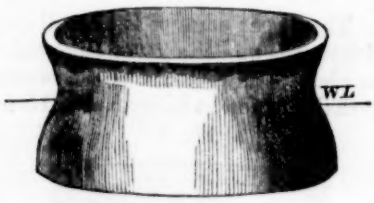
Section showing the amount of contraction. One-half the full size. The dotted lines show the original form.

The quality of the iron was afterwards tested by pieces taken from the upper and lower edges, and also from the centre; the fibrous condition had remained unchanged, the specific gravity had not altered appreciably, and there appeared to be no deterioration in any part of it.

Experiment 2.—Two hollow cylinders of wrought iron, 12 inches diameter and ½ inch thick each, and respectively 9 inches and 6 inches deep, were heated to redness, and cooled by half immersion in cold water twenty times; for effects see figs. 4 and 5.

Fig. 4.

Fig. 5.



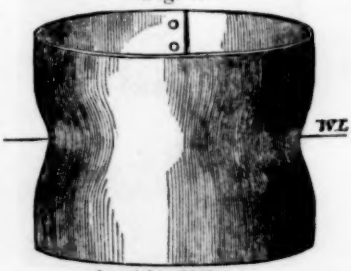
One-eighth of full size.

The 9-inch cylinder did not alter on the upper edge, cooled in air; but the lower edge, cooled in water, contracted ·6 inch, and the circumference, at about one inch above the water-line, was reduced 5·5 inches; the internal surface had increased in depth ·35 inch.

The small cylinder diminished ·7 inch on the upper edge, increased ·3 in. on the lower edge, and contracted 5·25 ins. at about 1 in. above the water-line; the internal surface had increased in depth ·3 in.

Fig. 6.

Experiment 3.—A cylinder of very thin wrought iron, so thin that it could not be welded, and was therefore riveted, of the same external dimensions as the 9-inch one of the foregoing experiment, was heated to redness and cooled by half-immersion ten times, in order to test the effect when the thickness of the metal was reduced as much as possible.



One-eight of full size.

The upper and lower edges were not altered materially, while the

greatest contraction took place on the water-line, instead of 1 inch above it as in the last experiment, and amounted to 3·5 inches. The depth measured on the curve had increased ·15 inch (see fig. 6).

Experiment 4.—Two wrought iron cylinders, exactly similar to those used in experiment 2, were heated and cooled by being immersed to two-thirds their depth in water twenty times.

The upper edge of the large cylinder was reduced 2·1 inches, and the lower edge ·9 inch; it contracted 5·9 inches at about an inch above the water-line, and the inside surface had increased in depth ·35 inch (see fig. 7).

Fig. 7.

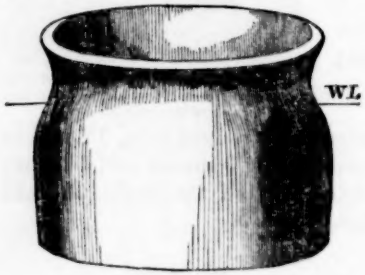
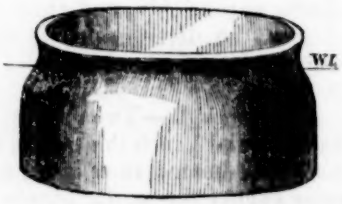


Fig. 8.



One-eigth of full size.

The upper edge of the small cylinder was reduced in circumference 3·6 inches and the lower edge ·65 inch, while the greatest contraction at about one inch above the water line was 4·6 inches; and the internal surface had increased ·15 inch in height (see fig. 8).

Fig. 9.

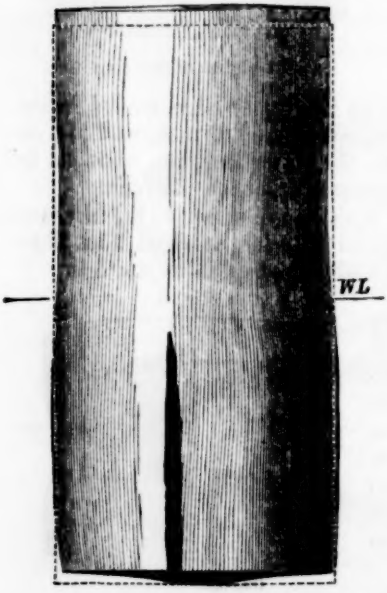
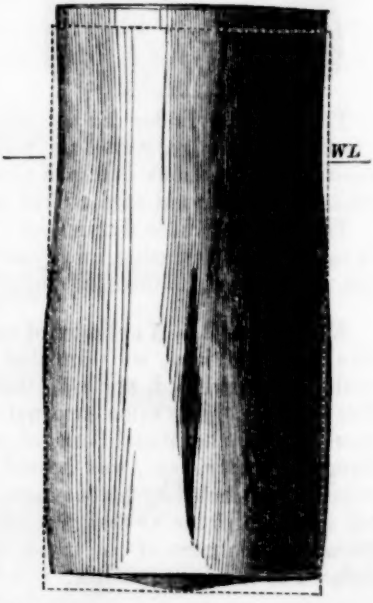


Fig. 10.



One-half of full size. The dotted lines indicate the original form.

Experiment 5.—A solid cylinder of wrought iron, 3 inches in diameter and 6 inches deep, was heated and cooled by being immersed half its depth in water fifteen times.

The greatest contraction took place a little above the water-line and on the lower edge, being in each case ·45 inch; the upper edge was reduced only ·1 inch.

A swell of metal took place on the two ends, but was greatest on the bottom, or that cooled in water, being ·15 inch in height.

The fibre of the iron opened at the fifteenth cooling (see fig. 9).

Experiment 6.—A wrought iron cylinder exactly similar to the last was cooled by being immersed to two-thirds its depth fifteen times.

The greatest contraction, amounting to ·4 inch, took place a little above the water-line; the upper edge was ·05 inch smaller, and the lower edge ·35 inch, while the swellings on the ends were nearly the same as in the last experiment (see fig. 10).

The separation of the fibre took place at the fifteenth cooling.

Experiment 7.—Two flat pieces of wrought iron, each 12 inches long, 6 ins. deep, and ·5 in. thick, were heated and cooled twenty times, one being immersed to half, and the other to two-thirds its depth in water.

That immersed one-half had contracted or become indented on the ends fully ·3 in.; the other had similar indentations, but to only one-half the amount. They were both turned up into the form of an arc, had thickened on their upper edges, and increased ·1 in. in thickness where the contractions on the ends took place (see figs. 11 and 12).

Fig. 11.

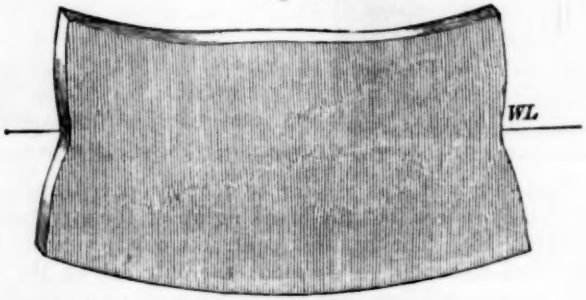
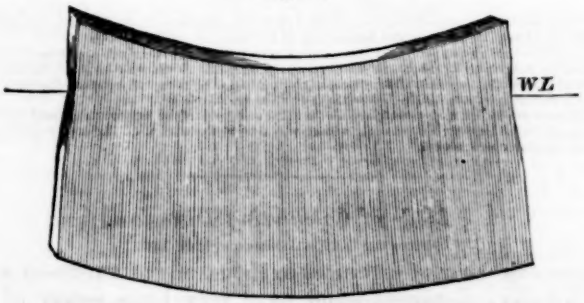


Fig. 12.



One-fourth of full size.

Experiment 8.—Two hollow wrought iron cylinders, 9 inches deep and 12 inches in diameter, were heated and cooled, one by simple exposure to air (fifteen times), and the other by total immersion in water (ten times). No alteration occurred in the form of either.*

Experiment 9.—A solid cast steel cylinder, of the same dimensions as that used in Experiment 5, was heated and cooled by half-immersion twenty times.

Fig. 13.

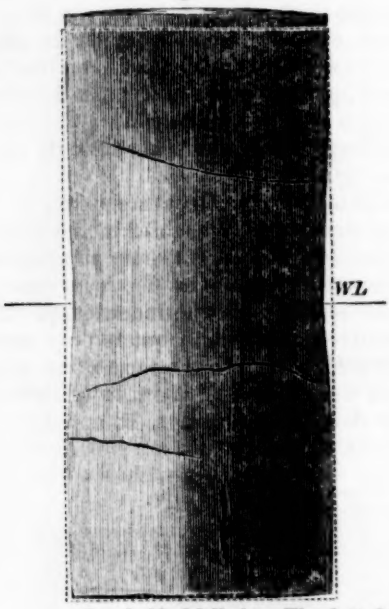


Fig. 14. [Top of Fig. 13.]

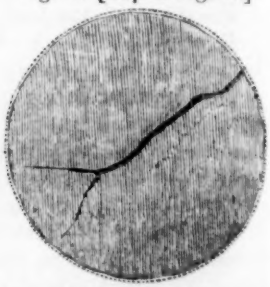
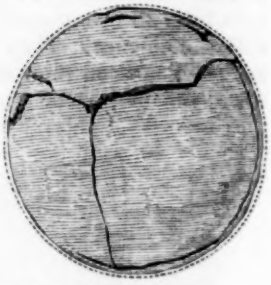


Fig. 15. [Bottom of Fig. 13.]



One-half of full size. The dotted lines indicate the original figure.

The effect obtained was similar to that produced upon the solid wrought iron cylinders, but the breaking up of the structure was different (see fig. 13). The greatest contraction was slightly above the water-line, and amounted to ·38 inch; the bulgings on the ends were ·075 inch, being much less than on the wrought iron cylinders.

(To be Continued.)

* The cylinder which was cooled in air weighed, before the experiment, 49 lbs. 14·5 ozs., and after the experiment, 49 lbs. 11 ozs., showing a loss by scaling of 3·5 ozs.

During the progress of the experiment, however, it was frequently weighed, and was found each time to have increased in weight up to the tenth heating, at which point it weighed 50 lbs. 1·125 ozs., or 2·625 ozs. heavier than it was at the commencement; from the tenth to the fifteenth heating the accumulated scales peeled off, and the weight was gradually reduced to that stated above.

That which was cooled in water weighed 50 lbs. 12·5 ozs. before the experiment, and 48 lbs. 14·5 ozs. at its conclusion, giving a loss of 1 lb. 14 ozs., which was due to the action of the water peeling off the scale each time the cylinder was cooled.

Mode of Calculating Distances.

From the London Athenæum, May, 1863.

Many people hear of distances in thousands of yards—a usual measure of artillery distances—and have very little power of reducing

them at once to miles. Now, four miles are ten yards for each mile above 7000 yards, whence the following rule: the number of thousands multiplied by 4 and divided by 7 give miles and sevenths for quotient and remainder, with only at the rate of ten yards to a mile in excess. Thus, 12,000 yards is 48 7ths of a mile, or 6 miles and 6 7ths of a mile: not 70 yards too great. Again, people measure speed by miles per hour, the mile and the hour being too long for the judgment of distance and time. Take half as much again as the number of miles per hour, and you have the number of feet per second, too great by one in 30. Thus, 16 miles an hour is 16 + 8, or 24 feet per second, too much by 24 30ths of a foot.

Decimalization of Weights and Measures.

From the Lond. Civ. Eng. and Arch. Journal, July, 1863.

The following is the bill now before Parliament for Decimalizing the existing system of Weights and Measures, and for establishing an accordance between them and those of foreign countries.* [The notes are by Professor Leone Levi, Barrister-at-Law]:—

Whereas, for the promotion and extension of our internal as well as our foreign trade, it is expedient that the Weights and Measures of the United Kingdom should be decimalized and made to correspond with those of other countries: Be it enacted by the Queen's most Excellent Majesty, by and with the Advice and Consent of the Lords Spiritual and Temporal, and Commons, in this present Parliament assembled, and by the authority of the same as follows:—

1. From and after the expiration of three years † after the passing of this act, the unit of the measure or length or lineal extension shall in all cases consist, of thirty-nine inches and thirty-seven thousand and seventy-nine hundred thousandth parts of an inch of the imperial standard measure, and shall be and is hereby denominated the new yard, or the "metre," wherefrom and whereby all other measures of extension, whatever, whether the same be lineal, superficial, or solid, shall be derived, computed, and ascertained, and all measures of length shall be taken in multiples or decimal parts of the said new yard or "metre."‡

2. The unit of the measure of surface shall be the square of the new yard except that the square of one hundred new yards shall be the unit of land measure, and shall be and is hereby denominated the

* This bill is introduced by Mr. Ewart, Mr. Adderley, Mr. Cobden, and Mr. Finlay, and stands for a second reading for the 1st July inst. Its principal object is to introduce into this country the metric system as it exists in France and most civilized countries, and this may be done in the easiest manner. The bill does not give a complete nomenclature of all the new weights and measures. It leaves this to be settled afterwards by the Board of Trade. The main point to decide now is, the introduction of the metric system, in lieu of the present uncouth manner of weighing and measuring. All other matters of detail will be discussed afterwards. It will be seen that the use of the new weights and measures is made by the act permissive only for three years, which may be extended to five, but obligatory after that term.

† The time may be prolonged to five years, or a clause may be added giving power to her Majesty to prolong the permissive use of the new system, as provided by the 14th clause, at the expiration of the three years should it be deemed necessary.

‡ In committee it will be better to define the length of the metre, independent of any number of inches of imperial standard measure, which of course would be abolished, and leave no further case for comparison. The metre is very nearly similar to the existing yard: the fifth part of the metre it just the link, the tenth part is the hand, and the hundredth part is the barleycorn or size. The double metre is equal to the fathom, five metres are equal to the rod or pole, twenty metres are equal to the chain, and two hundred metres to the furlong.

new acre or the "hectare," and all superficial and land measures shall be taken in multiples and decimal parts of the said units.*

3. The unit of the measure of capacity, as well as for liquids as for dry goods, shall be the cube of a tenth of the new yard, and the same shall be and is hereby denominated the new quart, or the "litre" and all measures of capacity shall be taken in multiples and decimal parts of the said new quart.†

4. The unit of weight shall be the weight of a new quart of distilled water, and the same shall be and is hereby denominated the "kilogram," the half of which shall be the new pound, consisting of one pound, one ounce, three drams, and three hundred and twenty-sixth thousandth parts of a dram avoirdupois; and all measures of weight shall be taken in multiples and decimal parts of the said kilogram; the thousandth part of the same shall be called the "gram," which, with its decimal parts and multiples shall be used for weighing bullion and precious stones, and for the purposes of pharmacy.‡

5. For the more convenient subdivision of weights and measures, it shall be lawful to use the double and the half of all the said units and their principal decimal divisions and multiples, as well as any other subordinate divisions which the committee of the privy council for trade may deem expedient.

6. The said weights and measures hereby established shall be and are hereby denominated the standard metric weights and measures.

7. Standards of the said new yard or the "metre," the said new quart or the "litre," and the said "kilogram," and of the respective multiples and decimal parts shall be made under the direction of the committee of the privy council for trade, and the same shall be duly verified by comparison with the standards in Paris, and copies and models of the same standards shall be sent to the Lord Mayors of London and Dublin, to the Lord Provost of Edinburgh, and to all counties, shires, stewartries, ridings, divisions, cities, towns, liberties, and places in which by law copies and models of the standard imperial weights and measures are, or are required to be, kept, and to such other places and persons as the president of the committee of the privy council for trade may from time to time direct.

8. All judges, magistrates, and other person or persons who now are or shall hereafter be authorized by law to order or provide copies of the present imperial standard weights and measures, shall at all times hereafter have like power and authority in every respect to order or provide copies of the standard metric weights and measures, and to charge the expenses thereof upon the fund or funds, money or moneys, that would have been liable in case it had been copies of imperial weights and measures that had been ordered or provided.

* The unit of superficial measure may be denominated a "square yard." The word "are" could not be used together with the "new acre," inasmuch as "are" "acre" are very like each other, and would lead to mistakes. Ten of the new square yards would be nearly equivalent to the rood. The new acre will be much larger than the present acre; whilst the statute acre is 4840 square yards, the new acre will be 11,960 square yards, but even now the Cheshire acre in use in many places in Lancashire is 10,240 square yards.

† The litre is very nearly equivalent to the quart, the half litre to the pint. One hundred litres are equal to the sack (corn), five hundred litres to the butt or pipe, and one thousand litres are equal to the tun.

‡ The definition of the kilogram and the half kilogram should have no reference to existing weights. The weight of the half kilogram is somewhat mistaken in the bill, and would be better expressed by 15432·34874 grains, of which our lb. contains 7000. One thousand kilograms make one ton.

9. All and every provision and provisions which are by law in force with respect to the inspection, verification, reverification, stamping, counterfeiting, and modes of conviction, with the penalty or penalties relating thereto, of the present imperial standard weights and measures, shall apply to and be in force with regard to the metric weights and measures in every respect as if the standard metric weights and measures were comprised in and designated by the imperial weights and measures in the act relating to such inspection, verification, reverification, stamping, counterfeiting, and modes of conviction, and the penalty or penalties relating thereto as aforesaid.

10. From and after the expiration of three years from the passing of this act, the imperial and all local or customary weights and measures shall be abolished, and every person who shall sell by any denomination of weights and measures other than those of the metric weights and measures, or such multiples or parts thereof as are authorized by this act, shall on conviction be liable to a penalty not exceeding the sum of forty shillings for every such sale.

11. From and after the expiration of three years after the passing of this act, if any person or persons shall print, or if the clerk of any market or any other person shall make any return, price list, price current, or any journal, or other paper containing price list, or price current, in which the denomination of weights and measures quoted or referred to, shall denote or imply a greater or less weight or measure than is denoted or implied by the same denomination of the metric weights and measures under and according to the provisions of this act, such person or persons, or clerk of the market shall forfeit and pay any sum not exceeding ten shillings, for every copy of every such return, price list, price current, journal or paper which he or they shall publish.

12. As soon as conveniently may be after the passing of this act, accurate tables shall be prepared and published under the authority of the committee of the privy council for trade, showing the proportions between the imperial weights and measures heretofore in use, and the metric weights and measures hereby established, with such other conversions of weights and measures as the said committee of the privy council for trade may deem necessary, and after the publication of such tables all future payments to be made shall be regulated according to such tables.

13. And whereas the weights and measures by which the rates and duties of the customs and excise, and other her Majesty's revenue, have been heretofore collected, are different from the metric weights and measures directed by this act to be used; it is hereby enacted, that so soon as conveniently may be after the passing of this act, accurate tables shall be prepared and published under the direction of the said committee of the privy council for trade, in order that the several rates and duties of customs and excise and other her Majesty's revenue may be adjusted and made payable according to the respec-

tive quantities of the legal standards directed by this act to be used, and that on the expiration of three years after the passing of this act the several rates and duties thereafter to be collected by any of the officers of her Majesty's custom or excise, or other her Majesty's revenue, shall be collected and taken according to the calculations in the tables to be prepared as aforesaid.

14. From and after the expiration of three months after the passing of this act and until the use of the metric weights and measures shall be made compulsory, the said weights and measures shall be deemed and taken to be legal weights and measures, and as such may be used for all purposes whatsoever.

—

The following reasons in favor of the bill are issued by the International Decimal Association :—

1. The uniformity in weights and measures which it has been the great object of the legislature to establish, is defeated by the vast variety of weights and measures in use in every part of the country and in many branches of trade.

2. The existence of so many weights and measures other than the imperial, proves that we do not at present possess a system adequate to the requirements of trade, and adapted to daily intercourse and to the purposes of science.

3. The metric weights and measures are universally admitted to fulfil the conditions of a sound and convenient system.

4. This system has been adopted not only in France, but in Belgium, Holland, Spain, Italy, Portugal, Germany, Switzerland, and Greece, and is rapidly extending over other parts of Europe and in America.

5. The increase of our trade with those countries which use the metric weights and measures renders its adoption by ourselves a matter of great practical importance.

6. The permissive use of metric weights and measures is highly expedient for the purpose of legalizing the transactions now carried on according to that system.

7. The country has already expressed itself in favor of the decimal method of calculation, on whch the metric system is based.

8. The metric weights and measures admit of binary divisions.

9. By decimalizing the weights and measures we best pave the way for the decimalization of our coinage.

10. Extensive inquiries have proved that the introduction of the proposed system would secure an immense saving of time in education.

11. The adoption of the metric system has been decidedly and unanimously recommended by a committee of the House of Commons, after most careful inquiry and discussion.

On the Relations between the Safe Load and the Ultimate Strength of Iron.

By Zerah Colburn.

From the London Artizan, April, 1863.

A great number of experiments have been made by many experimenters to ascertain the ultimate resistance of iron to tension and compression, and its strength has thus been determined with perhaps as much precision as is possible in the case of a material presenting almost constant variations of quality. Every engineer is now aware that, as an average result, the tensile strength of good cast iron may be taken as about 8 tons per square inch, and its crushing strength as 48 tons. Wrought iron of fair quality will bear not far from 22 tons per square inch in tension, while its crushing strength is variously stated at from 12 or 15 tons per square inch up to 28½ tons, the last named being given by Mr. Mallet as the result of experiments upon large hammered bars which bore but from 23 tons to 24 tons in tension.

When, however, we come to the question of safe working strength, much difference of opinion exists among engineers, the permanent supporting power of iron being variously estimated at from four-tenths down to one-tenth of its breaking strength. Thus when, some fifteen years ago, a royal commission sat to inquire into the application of iron to railway structures, the late Mr. Glynn, in his evidence, recommended that a cast iron bridge should never be loaded beyond one-tenth of its ultimate strength. The late Mr. Stephenson, with several other engineers, thought a ratio of one-sixth sufficient, while the late Mr. Brunel was satisfied with a ratio of from two-fifths to one-third; or, in other words, if a girder would just bear 100 tons of distributed load, he would put from 33 tons to 40 tons upon it, where Mr. Stephenson would allow not more than 17 tons and Mr. Glynn only 10 tons.

Were we now to have another commission entrusted with the same inquiry, it is not unlikely that as great a difference of opinion would be found still existing. For there is no acknowledged natural principle upon which the safe load of iron has yet been determined, and in the absence or oversight of such a principle each engineer must be governed by his own judgment of what is safe and prudent. It is true that the authority of the Board of Trade has been so far exercised in this matter as to have limited engineers, in the design of wrought iron railway bridges, to maximum tensile strains of 5 tons per square inch; and although it is commonly believed that with wrought iron a compressive strain of from 4 tons to 4½ tons corresponds to a tensile strain of 5 tons, the Board of Trade impose the same limit of strain for both the top and bottom chords of a wrought iron girder. The limit of 5 tons per square inch, it is hardly necessary to say, is an entirely arbitrary one, nor is it modified according to the quality of the iron and workmanship in a structure. Thus, in girder bridges, plate iron is used of which the breaking strength is occasionally not more than 18 tons per square inch. In punching the rivet holes, however, and irre-

spective of the loss of metal actually punched out, the solid iron remaining between the holes is injured, so much so that, in a series of experiments made many years ago by Mr. Fairbairn, the mean tensile strength of seven specimens was reduced from 52,486 lbs. per sq. inch before punching to 41,590 lbs. per square inch of solid iron left between the holes after punching,—more than 20 per cent. of the strength of the iron being destroyed by punching, a loss distinct from that of the metal actually punched out. Drilled rivet holes, it is satisfactory to know, are now being adopted in the best class of bridge work, but in bridges already erected and containing plates occasionally no stronger than 18 tons per square inch before punching, the loss of strength ascertained by Mr. Fairbairn, would diminish this to about 14½ tons for the net section of metal between the rivet holes. On the other hand, the best supension bridge links have a strength of from 26 tons to 28 tons per square inch of section, and yet the Board of Trade inspecting officers would not probably depart from the arbitrary limit of a maximum strain of 5 tons in either case. As far, therefore, as is necessary to meet the requirements of the authorities, good iron and sound workmanship go for little or nothing; and not only does this remark apply to the interference of the Board of Trade, but, in the case of Chelsea Suspension Bridge, the chains of which are believed to have a tensile strength of upwards of 25 tons per square inch, two of the leading members of our profession have declared that structure to be unsafe until it shall have been so strengthened that the greatest load which the heaviest traffic is likely to bring upon it shall not exceed 5 tons per square inch of the sectional area of the chains. The highest authorities, we are justified in supposing, would, at the same time, be satisfied with the same maximum strain in the chords of a plate girder bridge, even if the actual breaking strength of the solid iron between the rivet holes did not, as we have reason to believe it often does not, exceed 15 tons, or three-fifths that of the links of Chelsea Bridge.

From the illustrations given, the elasticity of solids appears to be no more than the range or play of the attractive and repulsive forces of matter, as variably exerted, but within the limits of rupture or crushing. Thus elasticity is the same in kind whether the repulsive or separating force be externally applied, or whether it be that of heat acting between the molecules of the body. If a bar of good wrought iron be stretched to the one-thousandth part of its length, corresponding, say, to a strain of ten tons per square inch, its elasticity will be fully excited or nearly so, and it will not support a much greater strain without taking a permanent set. It is true that, if the same bar of iron, when not under strain, be heated to from 150° to 200° above its normal temperature, it will also elongate by one-thousandth part of its length, and that without injury. But if this elongation take place under a compressive strain, or, if the iron, first raised in temperature by 200° and thereby elongated, be attached to two fixed points, and thus, while cooling, be made to contract under strain, it will be found that an elongation of not far from one-thousandth of the

original length of the bar is the most that can be borne without injury, even when that elongation is due to heat alone. But if the iron be first heated sufficiently to soften it, as railway tyres and gun hoops are heated, the particles will be re-arranged, and, within certain limits, without injury; but after the metal has once cooled below the temperature at which the particles have the mobility necessary for this re-arrangement, any further contraction around an unyielding object will be attended with permanent, and, there is reason to believe, injurious strain. Even in setting railway tyres, it is believed to be best to put them on cold, and under graduated pressure, and in the case of gun hoops, Captain Blakely and Mr. Mallet, who appear to be entitled to the credit of the modern system of the ringed construction of artillery, have always insisted upon the importance of a definite degree of shrinkage of each ring, so that the consequent strain shall not exceed the elastic limit of the material. Sir William Armstrong has stated that he does not consider any special accuracy essential in the distribution of the strains imparted by shrinking his gun hoops upon each other, but it may be questioned how far the failures of so many of the Armstrong guns have been due to neglect in this respect.

It would be interesting to know the precise manner in which a separating strain acts upon the molecules of iron, or rather to know the successive positions of the atoms during the application of the strain. We are, however, without any positive knowledge of the positions which the atoms assume in solidification and under subsequent forging, but the multifarious forms in which all atoms visibly crystallize serve to show us that they cannot all be at equal distances from each other throughout the whole body. If they were, the arrangement would be that of cannon balls in a triangular pyramidal pile. Could we visibly represent the atoms, as occupying the angles of an infinite number of equilateral triangles, we should understand that a linear strain acting to separate any two of the atoms would, at the same time, draw a third atom, if not a number of atoms partly between them. And when, from this intrusion, the repulsive force, or heat, always enveloping the intruding atom, had once overpowered the attractive or cohesive force existing between the two atoms thus strained apart, these would, in turn, cohere anew to the atom which had been drawn in between them, and thus we should have a permanent re-arrangement of the atoms, or, in other words, a permanent set, with permanent elongation in one direction, and permanent contraction in a plane at right angles thereto. That the atoms are thus drawn into parallel rows of straight lines, in many kinds of iron at least, seems evident from the appearance of fracture, which presents stringy collections of particles forming what is commonly called fibre, although there is great reason for doubting that any thing like fibre existed in the iron before it was broken. Mr. Kirkaldy's recent extensive experiments appear to show, as many others have shown, that iron may be made to break short or to break with an appearance of fibre, just according as it is broken with a sudden blow or a gradual pull. Something like fibre may be imparted, on a coarse scale, by repeated rolling or in wire-drawing,

but it is more probable that masses of atoms are thus drawn into strings than that any fibre is really imparted to the atomic arrangement itself.

It is commonly held that, within certain limits of strain, iron is perfectly elastic. There are high authorities, however, who maintain that iron takes a permanent set under even very moderate strains. If we are to understand that the set is exceedingly small, this may be true. The late Mr. Hodgkinson, for example, remarked, on the 381st page of his "Experimental Researches," that two cast iron beams took each a permanent set with weights respectively equal to one-fifty-seventh and one-eightieth of the breaking weight. In a discussion at the Institution of Civil Engineers, a Mr. Dines mentioned that he had tested upwards of 8000 cast iron girders for the late Thomas Cubitt, and that he found it hardly possible to apply a weight so small as not to produce some permanent set, one-twentieth of the breaking weight producing a perceptible set. In the experiments of the Iron Commission at Portsmouth a bar of annealed wrought iron 50 feet long was said to have taken a perceptible set with a weight of less than $1\frac{1}{4}$ tons per square inch. After this weight had been doubled, however, the set was still only perceptible; and notwithstanding that the elasticity of annealed iron is known to be inferior to that of unannealed bars, the whole set of the 50 feet bar was but the $\frac{1}{2\frac{1}{2}\frac{1}{0}}$ part of one inch, after a strain of $8\frac{1}{3}$ tons per square inch had been borne; and the set was but the $\frac{1}{2\frac{1}{0}}$ of an inch in 50 feet after a strain of 11·9 tons per square inch. Mr. Edwin Clark has experimented on a wrought iron bar 10 feet long and 1 inch square. Under a strain of 3 tons per sq. inch he gives a permanent set of nearly the $\frac{1}{1\frac{1}{0}\frac{1}{0}\frac{1}{0}}$ part of an inch in 10 feet. With 8 tons the permanent set is given as about the $\frac{1}{1\frac{1}{2}\frac{1}{8}\frac{1}{0}}$ of an inch in 10 feet, and it was not until a strain of 13 tons per square inch had been applied that a set of $\frac{1}{32}$ inch in 10 feet became apparent. With such exceedingly minute measurements, we may, perhaps, doubt if there was really any permanent set at all, with strains under 9 or 10 tons per square inch. An increase of temperature in the bar of perhaps a single degree, while the measurements were being made, would more than account for some of the reported sets, even under considerable strains. Thus Mr. Edwin Clark gives the permanent set of his bar, after a strain of 8 tons per square inch, as the $\frac{1}{1\frac{5}{3}\frac{1}{8}\frac{1}{4}\frac{1}{6}}$ part of its length, and this is almost exactly what the extension of the bar would have been had its temperature been raised but a single degree between the observations. Iron is heated in the very act of straining it, and a sudden breaking strain will generally leave the broken ends too hot to be handled. Such a slight apparent extension might also have occurred while the shackles by which the bar was strained were coming to their bearings. But even if such a microscopic permanent set really existed, it is one of which no engineer would take the slightest serious notice as affecting the strength of the bar in which it was observed. With the means of measurement commonly employed by engineers, ordinary wrought iron is seldom permanently stretched until after it has borne strains of upwards of 8 tons per square inch. In

seven experiments by Professor Barlow, on wrought iron bars 10 feet long, two of them retained their full elasticity under a strain of 11 tons per square inch, three bars bore 10 tons without injury, while one bore 9½ tons, and another, made from old furnace bars, did not retain its elasticity beyond a strain of 8¼ tons per square inch. All the links for Pesth Suspension Bridge, upwards of 5000 in number, and 12 feet long from centre to centre, were tested without permanent set up to 9 tons per square inch, and those of Chelsea Suspension Bridge were tested, without permanent elongation, up to 13½ tons per square inch. Mr. Edwin Clark, from the results of his experiments, considers that the limit of elasticity of wrought iron is 12 tons per square inch, and this appears to have been adopted by him both for bars having a breaking weight of 24 tons and for plates having a breaking weight of 20 tons. Every chain cable purchased by the Admiralty is tested up to 11·46 tons per square inch of the metal in each side of the link, the standard test being 630 pounds for each circular one-eighth inch of the diameter of the iron of which the cable is made, one-half of this strain coming upon each side of the link. The iron of which the cables are made does not, as a rule, take any permanent set when strained to this amount, or, to say 11½ tons per square inch. Mr. Howard has stated that the best iron begins to stretch permanently under about 10 tons per square inch in 10 feet lengths, although he occasionally tests up to 15 tons or 16 tons per square inch, the breaking weight being from 26 to 28 tons. Mr. Mallet, about four years ago, presented to the Institution of Civil Engineers the results of a valuable series of experiments on wrought iron and puddled steel, from which it appeared that the elastic limit and the breaking strain under tension were, in the case of certain samples, as follows:—

	Elastic limit.	Breaking weight.
	Tons.	Tons.
Hammered slab or bar, 12 ins. by 4 ins. . .	15·312	24·062
" bar.	14·219	22·969
Rolled slab or bar, 12 ins. by 4 ins. . .	10·937	22·969
" bar, ...	10·937	22·969
Fagoted forged slab, 4 feet by 1 foot, . .	8·750	18·594
Original fagot bars, Horsfall gun, . .	12·031	21·875
Longitudinal cut, forged mass, . . .	9·844	19·688
" " " " . . .	10·937	17·900
Circumferential " " . . .	6·562	16·406
" " " . . .	5·470	16·716
Transverse " " . . .	3·281	6·562
Charcoal rolled bar from borings from the Horsfall gun,	5·470	22·321

Sir Marc Brunel made a number of experiments on Yorkshire iron, hammered to small dimensions, or from ⅜-in. to ½-in. square. A very high elastic limit was obtained, as follows:

Mean of ten bars began to stretch with 22·2 tons per square inch, the mean breaking weight being 30·4 tons per square inch. With ten

other bars the mean strain at which they began to stretch was 24·4 tons, the breaking strength being 32·3 tons per square inch. It is to be borne in mind, however, that these bars were reduced by the hammer only at the centre of their length, and that therefore, the stretching could be observed upon but a very small part of their length. Mr. John A. Roebling, the engineer of the Niagara Suspension Bridge, has made experiments upon bars similarly drawn down to ¾-in. square at the centre, the breaking weight being 33 tons per sq. inch; these bars bore a strain of 20¼ tons per square inch with visibly stretching, and when no jar was given to the bars they would support the strain for a week. Upon any vibration, however, the bars immediately took a permanent set.

Under strains, however, considerably within the elastic limit, a gradual re-arrangement of the particles of the iron commences; and if the strain be continued sufficiently long, permanent set will after awhile take place. The late M. Vicat, whose work on limes and mortars is so well known, began as early as 1830 to investigate the effect of continued strains on unannealed iron wire. He applied various strains to similar wires of a known breaking strength, and continued these strains from July, 1830, to October, 1833. One wire was strained to one-fourth its breaking weight, but beyond the elongation which at once took place no additional stretching occurred in thirty-three months. A second wire was strained to one-third of its breaking weight, and in thirty-three months it stretched at the rate of 2⅜ parts in every 1000 parts of its length, this stretching being additional to that which took place as soon as the weight was applied, but which, of itself, was not sufficient to immediately produce any permanent set. Under a strain of one-half of the breaking weight another wire was stretched rather more than 4 parts in every 1000 parts of its length. Under a strain of three-fourths of the breaking weight a fourth wire stretched, in thirty-three months, 6⅛ parts in every 1000 parts of its length, and then broke, which circumstance terminated the experiments. M. Vicat's account of them appeared in the 54th volume of the second series of the *Annales de Chimie et de Physique*. It is to be regretted that, in place of the constantly recurring experiments upon the breaking strength of iron, and which, as is already beginning to be understood, give us but a very partial knowledge of its available working properties, we have not a larger experimental acquaintance with the continued supporting power of iron, as afforded by experiments similar to M. Vicat's. Mr. Fairbairn, it is true, made an extensive series of experiments between the years 1837 and 1842, to ascertain how long bars of cast iron would support weights equal to about nineteen-twentieths of their breaking weight. By taking care to prevent any vibration in or about the bars, several of them continued, for five years and upwards, to support nearly their full breaking weight. Their deflection steadily increased, however, during the whole time, and Mr. Fairbairn has stated that some of these bars afterwards broke with but one-twentieth of their original breaking weight. As bearing upon the last mentioned circumstance, it may be remarked

that M. Vicat, writing in 1833, observed that M. Henri, an engineer serving in Russia, had already shown that iron which had once withstood a great proof strain, often broke some time afterwards under a much less strain. This fact must indeed have been known to practical men even earlier than in 1830.

(To be Continued.)

Proceedings of the Association for the Prevention of Steam Boiler Explosions, Manchester.

From the London Mechanic's Magazine, February, 1863.

(Continued from p. 104.)

Water-Gauges.—The recommendation previously given to fix duplicate water-gauges to every boiler, and to have the passage in the necks as large as possible, can only be repeated, in the present instance, with the additional force which another year's inspection gives, and many furnace crowns would have been saved by the timely adoption of these simple precautions. The taps of glass water-gauges are almost always found to leak; this can be greatly remedied by having them fitted with nut-glands packed with a little cotton, while the grit, which so soon cuts away the plugs, would be much lessened by the adoption of surface blowing-out.

Pressure-Gauges.—All the pressure-gauges fixed to the boilers under inspection are checked by a standard indicator at each of the inspector's visits, provided that the boilers are fitted with the necessary tap. Thus the accuracy of most of the pressure-gauges passes constantly under review.

Generally, they are found to indicate too high a pressure, but, in some cases, as much as from 10 to 15 pounds too little; the first error leading to their being disregarded, and the second to actual excess.

The pressure-gauges under inspection are, with but a few exceptions, of four classes, namely, the natural mercurial column gauge; the mercurial differential gauge; the dial gauge; and the compressed air gauge.

The natural mercurial column gauge stands first upon the list for accuracy, as its simple and direct construction would indicate.

The differential mercurial gauge is of inverted syphon construction, the short leg being of larger diameter than the long one, and thus the mercury has less travel in the former than in the latter. The indications of pressure are read off from the short leg, which considerably reduces the length of the index scale of pounds, and those of the best class of this gauge are very legible. In one class of differential gauge, however, the mercury enters the glass indication tube, which becomes very much discolored in consequence, and, in some cases, quite opaque; while at the same time the glass stands off so far from the index face, that it can only be read accurately when the eye is placed on a level with the upper surface of the mercurial column. In another class of this differential gauge the mercury does not enter the glass tube at all,

but the pressure is indicated by a floating pointer, so that no discoloration of the glass takes place, and the gauge is always legible.

Dial gauges are very compact, and can be fixed directly in front of the boiler, just in sight; while those of the best class are very legible; care should be taken, however, not to fix them too near the boiler face, or else to put a piece of wood between the two, so as to prevent their becoming heated, or otherwise their indications will be affected.

The compressed air gauge, in which a syphon column of mercury, as a piston, acts upon an air cushion, is found to be universally incorrect, and is quite unworthy of confidence.

In conclusion, while the natural mercurial column gauge must be allowed to stand the highest for abstract accuracy, yet the best description of the mercurial differential column gauge, as well as that of the dial gauge, are but slightly inferior to it practically, and are more easily read; while the dial stands pre-eminent for compactness, especially at high pressures, which becomes of importance in a long series of boilers, when each is fitted, as it is always desirable should be the case, with its own independent gauge.

Defective Blow-out Apparatus.—It has already been stated, under the head of "Corrosion," how much injury is frequently done to the bottom plates of boilers by defective joints of the blow-out pipes; to remedy which a short block should be riveted to the boiler, and the pipe bolted to it instead of direct to the shell. These pipes, which are generally of elbow-shape, should not be bound by the brickwork, since the settlement of the boiler is apt to strain them, and cases have occurred in which they have been fractured in consequence. From this, in one instance, considerable corrosion ensued; and in another, not under the inspection of this association, in which the fracture was sudden and complete, scalding resulted to two or three persons.

Many blow-out taps are dangerous to use for want of suitable discharge pipes to carry off the waste water, and in some boilers the water spaces have been found to be completely choked with sediment, from neglect of the most simple precautions with regard to the use of the blow-out apparatus. This subject has been so constantly alluded to that repetition would be tedious, though perhaps hardly unnecessary; it will, therefore, only be added that brass gland taps, recommended in previous reports, are still found to give satisfaction, and to be more certain in their action than either sluice or mushroom valves.

Incrustation.—Some advance has been made during the past year in the prevention and removal of incrustation, although much yet remains to be done. It is too frequently concluded that incrustation and corrosion are not to be found in the same boiler, and that the plates beneath the scale are protected. Such, however, is by no means found to be universally the case, and frequently, on removing the scale, grooving or other evidence of corrosion is discovered on the surface of the plate beneath it. An inspection of a boiler, therefore, coated with incrustation, must always be unsatisfactory, not to mention the injury to the boiler itself, as well as the loss of heat that results from it.

The remedy adopted for this evil, in marine boilers, namely, "sur-

face blowing-out," has been during the past year frequently brought before the attention of the members, and a drawing made of a simple unpatented arrangement, and placed at their disposal. A very considerable number have availed themselves of this, while as many of the manufacturing engineers as have wished to do so have furnished themselves with copies. In consequence of this, several of these scum pipes have been applied; the exact number is not known, but one firm among others may be mentioned, who have fixed one of these scum pipes to each of their nine boilers, and with the most satisfactory results.

This is not, however, the only description of scum pipe adopted. The subject of "surface blowing-out" has been taken up by others, and two varieties of apparatus patented, and somewhat generally introduced. It is thought that this diversity will rather prove of advantage than otherwise; and now that the general principle of "surface blowing-out" has been called attention to, the more individual ingenuity is directed to the details of the apparatus the better. A more minute reference to the construction of these scum pipes was made in the monthly abstract of October last; and now that these three classes have been in operation for some time, it is thought that the results of their working may shortly be made a matter of comparison, which, as soon as opportunity offers, will be communicated to the members.

The use of soda for the prevention of incrustation is found of considerable advantage, and increasingly adopted. It is, however, better introduced in small regular doses, than in large infrequent charges. In many cases there might be fitted to the suction pipe of the feed pump a funnel mouth, by means of which the requisite charge could be introduced to the boiler without difficulty; its rate of ingress being regulated by a tap between it and the suction pipe. In some cases a separate feed pump has been adopted, fitted with a small cistern containing a day's supply, and this arrangement has been found to work most satisfactorily.

In conclusion, there are but few cases of incrustation which the use of soda, combined with regular blowing-out from the surface of the water, will not check.

Construction of Boilers.—The consideration of the previous defects, to which the boilers under inspection have been found to be liable, will, it is trusted, prove of assistance to members wishing to lay down new boilers, as well as to those whose business it is to construct them.

But it is thought, however, that a further service yet might be rendered. Such ample opportunity has been enjoyed of seeing when in work, as well as of examining while at rest, considerable numbers and varieties of boilers, and such full information has been collected with regard to them by the association, that it is thought if the best proportions were collated, and put together in the form somewhat of a specifiation, it would prove of more assistance still than observations and analyses of defects alone; not by any means a minute and technical specification, but a systematic explanation of such proportions as have been found to exist in those boilers giving the best results and

needing the least repair. It was intended to include this in the present report, but finding that it could not be given complete, it is reserved for insertion in the printed monthly reports which circulate amongst its members.

Explosions.—It is to be regretted that no means exist of ascertaining the whole number of steam boiler explosions that occur throughout the United Kingdom, and there can be no doubt that many are never recorded at all. There are known, however, to have occurred during the last year no less than 30 explosions, from which at least 87 persons have been killed, and 89 injured. Of the number of lives lost by some of the above, no account could be obtained; while, from one of them, as many as 29 persons were killed and 12 injured; from a second 12 were killed and 24 injured; and from a third 6 were killed and 8 injured.

The following list gives the description of boiler to which the explosions have occurred, with the number of each class, as well as of the persons killed and injured:—

Four haystack boilers—12 persons killed, 5 others injured.

Six plain cylindrical egg-ended boilers—6 persons killed, 6 others injured.

Three iron-works boilers—47 persons killed, 44 others injured.

Three plain single-flued Cornish boilers—2 persons killed, 3 others injured.

Two plain double-flued Lancashire boilers—4 persons killed.

Three locomotive boilers, of tubular construction—4 persons killed, 5 others injured.

One agricultural boiler, of tubular portable construction—4 persons killed, 4 others injured.

One kitchen-range boiler—1 person killed.

Also, seven other boilers, of the construction of which no reliable information could be obtained, and from the explosion of which 7 persons were killed and 22 others injured.

The haystack boilers, referred to above, were externally fired, and exploded through the failure of the part exposed to the action of the fire.

The plain egg-ended boilers, fired underneath, were found in all cases to have exploded from the rending of the transverse seams of rivets. One of these boilers exploded at the bottom of a coal mine, and in another case three boilers working side by side exploded simultaneously. Details of all these have already been reported in the monthly abstracts for February, March, and August, respectively, so that further particulars need not now be given.

The iron-works boilers were all heated by the flames passing off from the iron furnaces, which played not only upon the external shells of the boilers, but also through their internal flues.

The first of these was what is termed an "upright furnace" boiler, in which the flames, passing off from sometimes as many as four iron furnaces, impinge upon the exterior, and then pass into an interior

descending flue. In this case the crown of the descending flue collapsed from original defective construction.

The second explosion occurred to a precisely similar boiler, but in this case the external shell gave way at the seams, upon which the flames from the iron furnaces impinged.

The third boiler was a plain single-flued "Cornish" one, fired externally by the flames passing off from two iron furnaces, and internally by those passing off, through its flue-tube, from another. The explosion was caused by collapse of the internal flue-tube, arising from defective construction, and might have been prevented had the flue been strengthened either with flanched seams, or hoops of angle-iron, T-iron, or other suitable form.

Each of the three iron-works boilers was personally examined subsequently to its explosion, and full particulars were given in the March, April, and December monthly abstracts.

Of the three explosions which occurred to plain "Cornish" boilers, one was caused by collapse of the flue-tube, consequent upon shortness of water. This appears to have been caused by carelessness, the gauge-glass having been broken. The shell of the boiler was uninjured, and the only damage done was by the percussive action of the steam and water, in a direct line with the furnace-tube.

Of the other two, no reliable information could be obtained; they are reported, however, to have failed at the front end plate.

Both the explosions which occurred to boilers of the plain double-flued "Lancashire" class, were caused by external corrosion of the plates, which were so eaten away in one case as to be reduced in thickness to the sixteenth of an inch, and in the other to that of a sheet of paper.

One of these boilers was under the inspection of this association, but the opportunity had not been afforded to its inspectors of making the regular annual "thorough" examinations, the importance of which has been so repeatedly called attention to in the reports. This subject was gone so fully into in the monthly report for July last, shortly after the explosion happened, that it is needless to repeat the details here; while the particulars of the other, which also was personally examined, will be found in the monthly report for last December.

The locomotive boilers, in every case, exploded from thinning of the plates, caused by internal corrosion, it being a general practice in the management of locomotives only to make a thorough internal examination of the shells of the boilers, when the flue-tubes are renewed. This, in some cases, has allowed an interval of as much as seven years to elapse between one examination and another, during which time the boiler has been working in a state of complete uncertainty, the actual condition of the plates being unknown. The use of the hydraulic pressure is objected to by several locomotive engineers, though not by all; it is a point which has provoked a good deal of discussion, and is too lengthy to enter upon on the present occasion. It may, however, be stated in brief that no case has been met with, in the experience of the

association, in which injury has resulted from the judicious application of this test, and also that no opportunity will be lost of contributing any information on the subject that the experience of the association may afford. It is one of considerable interest, and affects the safety of the whole traveling public.

The kitchen-range boiler exploded from accumulated pressure, the taps of both the inlet and outlet pipes being closed at the same time, in consequence of which there was no escape for the steam, there being no safety-valve.

Of the cause of the explosion of the agricultural portable boiler, as well as those which occurred to the remaining seven at the bottom of the list, no reliable information has been received, while the distance at which nearly all of them happened precluded personal examination.

The causes of the above explosions may be systematized as follows:

Of 30 explosions which happened during the year 1862, 11 occurred to externally fired boilers from failure of the plates exposed to the action of the fire; 3 resulted from internal corrosion, and 3 from external; in addition to which, 4 were due to improper original construction, one to shortness of water, and another to accumulated pressure through want of a safety-valve; while 7 occurred at a distance which precluded a personal investigation of their causes, at the same time that no reliable information could be obtained with regard to them.

It may be added, that the explosion which occurred to a double-flued "Lancashire" boiler, and from which one life was lost, is the third fatal explosion which has happened to any of the boilers under the inspection of this association, since its establishment eight years ago; to which should be added three cases of collapse of furnace flues, not attended with any serious consequences, and which arose in two instances, if not in all three, from shortness of water. During this period 712 dangerous defects have been pointed out in the boilers under inspection, from which serious injury might have arisen in each case; while, upon limited inquiry only, it has been found that no less than 213 explosions have occurred in that time to boilers not under the inspection of this association, which have been attended with the loss of 472 lives, in addition to serious injury to 512 persons, and considerable damage to property.

Engines.—The depressed state of trade during the past year has so disorganized the ordinary working of most of the mills, that it has been found impossible to draw up a reliable comparative table of the economic duty of the engines. Indicator diagrams alone, however, from most of the engines under inspection, never afford the necessary data for correct comparison, since so much steam is drawn off for purposes other than that of motive power. It becomes, therefore, highly desirable that water metres should be fixed to each series of boilers, so as to ascertain the amount of water evaporated. This would enable a comparison to be made of the evaporative power of different boilers, and of the value of different coals, while at the same time the diagrams would afford an indication of the working of the engines.

Two pair of engines, built during the past year, have had their cylinders fitted with steam jackets; and a superheating apparatus, for raising the temperature of the steam in its passage between the boiler and engine, has been introduced in two or three instances. The object of both these arrangements is economy of fuel, and it is intended, as soon as possible, to investigate the results obtained, in order to communicate them to the members.

A "surface-condenser" is being constructed for a pair of beam-engines, and will, it is expected, be put to work early this year. "Surface-condensation" is the most radical preventive of incrustation, since, whatever the character of the condensing steam may be, this condenser returns to the boiler distilled water; the same quantity, with the exception of a small amount of waste, being used again and again. There are many cases in this district where this will prove valuable; and the results of the application in the present instance will be a matter of considerable interest to many of the steam users of the district.

Conclusion.—A very brief recapitulation may be allowed in conclusion, of some of the points attained during the past year.

"Surface blowing-out" has made considerable progress. "Steam-jackets," so long discarded in this district, have been revived, and "superheating" introduced, while a "surface-condenser" is about to be applied.

Although these arrangements are not in general use here, they have been fully tested elsewhere, and it is thought that much may be gained by importing, as it were, into this district, the engineering experience of others. For instance, the "steam-jacket" has, in combination with the use of highly-expanded steam, been the principal element in the attainment of that economy for which the Cornish engine has for so long since been notorious, while "surface blowing-out" and "surface-condensation," as well as "superheating," are due to marine engineering practice, which has developed a higher economic result than that generally obtained in this district.

Although it is true that all really sound and beneficial mechanical arrangements, practised in one district, will in time surely find their way into and secure for themselves adoption in others; yet it is thought that this association can do much to hasten this process—too frequently a tardy one—by circulating upon these points information among its members; and to assist in doing which, as far as it lies in my power, will always be regarded by me not only as a duty, but a source of satisfaction and pleasure.

It is trusted that during the present year the mechanical arrangements just referred to will be fully tested, and general confidence and adoption secured in this district, for such of them as prove worthy of it; so that the desire expressed at the conclusion of the last annual report may be realized, namely—"That no year may be allowed to pass, without a decided mark of progress being clearly stamped upon the engineering practice of the district by this association." For the accomplishment of this, however, the co-operation of the members is absolutely necessary. Comparative returns of the working of engines

cannot be made, unless the members have their engines indicated; neither can the consumption be calculated without accurate returns, nor the evaporative power of the boilers arrived at without the application of water metres.

Centrifugal Pumps.

From the Lond. Mechanics' Magazine, December, 1862.

We have received the following useful letter, addressed to Messrs. Gwynne & Co., of Essex wharf, by Mr. Zerah Colburn, Civil Engineer :—

Messrs. Gywnne & Co. Gentlemen :—In accordance with your instructions of the 27th ultimo, I at once examined your engines in the International Exhibition.

The engines and pump were run experimentally on the 29th, 30th, and 31st of October, and on the 1st and 3d instant (November).

The only trials of your pump, upon the general results of which I am disposed to place much reliance, were those made on the 4th inst.

The trial of greatest interest was to ascertain the efficiency of the pump, both as to the absolute discharge, and as to the proportion which the useful work done might bear to the power expended.

The engines and pump being run continuously at the rate of 200 revolutions per minute, the water in the lower tank fell 1 ft. 9¼ ins. below where it originally stood before the pump was started, and the water was raised in the upper tank to a maximum height of 1 ft. 8½ ins. above the crest of the weir, over which flowed an unbroken stream 9 ft. 8⅝ ins. wide, and 12½ ins. thickness, as measured over the crest of the weir, and occasionally splashing against a board placed 15 ins. above the weir. The water, as it rose in the upper tank, presented a curved surface, the highest point of which corresponded to a maximum lift of 20 ft. 6⅝ ins. above the level at which the water stood at the same moment in the large tank below. It was only the water which rose in, and near the centre of the 30 in. pipe, however, which reached this extreme height. It will, however, be making an ample allowance for the somewhat inferior velocity of the water rising in contact with the inner surface of the pipe, if we take the mean lift of the whole body as 20 ft. 4⅝ ins. or to a level of 1 ft. 6⅛ ins. above the crest of the weir. The velocity of the water ascending the pipe, altogether 20 ft. long, was rather more than 12 ft. per second, and thus the friction of the water in the pipe (the overcoming of which friction formed part of the true "duty" of the pump) would, by Wiesbach's formulæ (accepted by most English engineers), be equivalent to an additional lift of 4½ ins., making the total corrected lift 20′ 8¾″ = 20·73.

The corrected mean rise of the water above the crest of the weir, 1 ft. 6⅛ ins., would be perhaps the least which, under the circumstances, could have been expected to give an overflow 12½ ins. thick on the weir itself. Taking the true head as 1 ft. 6 ins., the full theoretical discharge, without loss of any kind, would be 5733·22 cubic feet, and

as the co-efficient to be applied in obtaining the actual discharge, appears from a great number of experiments, by many and high authorities, to be ·57, the actual discharge would be 3268 cubic feet per minute. The circumstance is to be mentioned, that a certain quantity of air was mingled with the water, over and above that naturally diffused in water, but no estimate can be formed of this quantity, and the discharge may be set down, therefore, as 91·03 tons, raised 20·73 ft. high per minute, or an actual "duty" of 128·1 horse power.

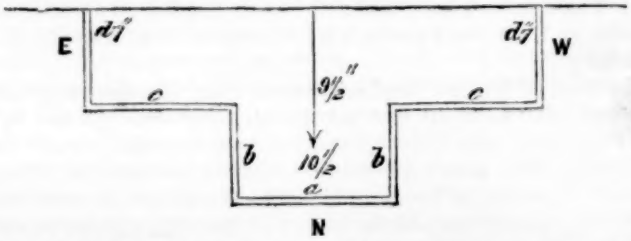
Diagrams, taken at the same time from the engines, showed a mean pressure, exclusive of back pressure, of 26·66 lbs. per square inch. Deducting the ascertained friction of the engines running light, which was 1½ lbs. per square inch, and deducting one-seventh of the remaining pressure, as the friction due to the load itself, an estimate made by Pambour, and adopted by Professor Rankine and others, the net effective pressure usefully exerted in work was 21·56 lbs. per square inch, corresponding at 200 revolutions per minute to 154 effective horse power.

Thus the work done by the pump represented 83·18 per cent. of the power actually applied in driving it.

On the 4th and 5th instant, also, in accordance with an understanding between yourselves and Messrs. Easton, Amos, and Sons, I attended to note the working of their engines and centrifugal pump in the western annex. The engines have cylinders nominally bored to 20 (but which are slightly larger), 24 inch stroke, and have a large bevel wheel with 124 teeth on the engine-shaft, which gears into another wheel of 52 teeth on a vertical pump shaft. The diameter of the pump, as given to me by the makers, is 4 ft. 5 ins., and the makers, who have had much experience with the working of these pumps, also stated the capacity of their pump in the Exhibition as equal, at 118 revolutions per minute, to a discharge of 100 tons of water per minute on a 6 ft. lift.

The next trials were made to test the absolute efficiency of the pump, both as to the quantity of water raised, and as to the proportion of useful work done to the power applied.

The engines being run at 52 revolutions per minute, corresponding to 124 revolutions of the pump, the total lift of the water was found to be 7 ft. 0⅞ in., or say 7·0833 ft. The rim of the upper tank, over which rim the water was discharged, was of the following shape :—



The total length of the line of overflow, as measured around the inside of the tank, was 42 ft. 1 in.; the northernmost inner edge being

6 ft. and ½ in. long. The flanch forming the edge of tank was 2½ ins. wide all round, and was horizontal on its upper surface. The water entered the upper tank in a horizontal direction, indicated by the arrow on the sketch, and through an opening 5 ft. 10½ ins. wide. The height of the water above the upper edge of the tank, when the pump was making 124 revolutions per minute, was found to be as marked in figures on the sketch—to wit, 9½ ins. in the middle of the larger part of the tank, 10½ ins. in the middle of the fore part, and 7 ins. in each of the side bays of the tank. The height of the water over the centre of the pump was 13½ ins. above the edge of the upper tank. The actual thickness of the stream overflowing on the northernmost edge was 8 inches, and on the easternmost and westernmost edges 5½ ins. In calculating the discharge I have, in order to allow for the initial velocity of the water approaching the edge marked *a*, considered the discharge over that edge to be due to the full head over the pump or 13½ inches. The discharge over the sides *b b* has been calculated, as due to a true head of 10½ inches, as measured by holding a long straight edge across the tank, and so as to skim the water.

The direction of the current in the tank being parallel to the sides *b b*, the discharge over them would really be somewhat less than that due to the full head of 10½ ins., but I have made no deduction on this account. For the sides *c c* and *d d*, a true head of 7″, as obtained by means of the straight edge, is taken. These sides, being out of the line of the current setting through the tank, I have made no allowance for the initial velocity. The true head acting to produce a discharge over the four sides *b b* and *c c* would no doubt be intermediate between 10½ and 7½ inches; as for some part of the length of the sides *c c* the head must have been greater than 7 inches. If, however, the mean of these heads, or 8¾ inches, be taking as the true head acting over the four sides *b b* and *c c*, the total calculated discharge would be rather less than that by taking the heads 10½ ins., and 7 ins. respectively. With the desire, therefore, of not under-estimating the discharge of a pump, which must be looked upon as a rival of your own, I have adopted the calculation giving the greater discharge, taking a head of 10½ ins. for the whole length of the two sides *b b*, and a head of 7 ins. for *c c* and *d d*. The co-efficient of discharge under an equal head, would be considerably less for a weir 2½ ins. wide than for one ¾-in., but as there was a less depth of head acting upon Messrs. Easton, Amos & Son's weir, I have taken the same co-efficient as in estimating the discharge from your pump, viz: 57 per cent. of the full theoretical discharge.

In the case of Messrs. Easton's pump, then, the discharge over the edge *a* was 1319·11 cubic feet per minute, that over the two sides *b b* 1796·31 cubic feet per minute, and that over the four sides *c c* and *d d* 1938·22 cubic feet, making 5053·64 cubic feet per minute for the total discharge. Air was, of course, present in the water, the total body of water falling, and the superficial extent of the falling sheet being much greater than from your pump, although from the low lift the velocity at the end of the fall was probably not more than two-thirds as great

as in the case of your pump. As it is impossible to estimate correctly the proportion of air, I merely mention its presence, and allow 62·4 lbs., as in the case of your pump, for each cubic foot of discharge. This gives Messrs. Easton's pump a discharge of 140·77 tons of water per minute, or nearly 41 per cent. more than the makers have claimed for it, and as the lift was 7·0833 ft., instead of 6 ft., the work done was equal to 67·68 horse power, or 63·6 per cent. greater than the makers claim. I cannot quite believe that had the water been discharged into a gauge tank, the quantity actually thrown per minute would have weighed 140·77 tons; but with the wish not to under-estimate, for your guidance, the capabilities of a pump occupying the place of the rival to your own, I have, wherever any doubt has arisen as to the true mode of calculating the discharge, adopted that giving to Messrs. Easton's pump the highest result.

The power exerted at the same time by Messrs. Easton's engines was ascertained. Diagrams, taken from both the top and bottom of both cylinders, are herewith annexed. The diagrams from the bottom of the cylinders are nearly worthless, however, on account of the length and comparatively small diameter of the pipe through which steam was carried from the bottom of the cylinder to the indicator, the latter being placed at the top of the cylinder, and quite 2½ ft. from the bottom.

The pressure at the top of the cylinder has been taken as the true pressure, the engine man having stated that the slide valves were carefully set to admit steam equally to the top and bottom of the cylinder. The mean effective pressure, therefore, at 52 revolutions, is 29·53 lbs. The indicator made by Messrs. Elliot Brothers, was, I was assured, and have reason to believe, frictionless, so that no deduction is to be made on account of indicator friction. There was no means of ascertaining the friction of the engines; but this must have been somewhat less, as measured in lbs. per square inch of piston, than in the case of your own engines. Messrs. Easton's engines had a stroke and connecting rods of good length, a parallel motion, instead of cross-head guide blocks; the connecting rod, instead of taking on to a crank, of the full diameter of the shaft, as in your engines, grasped a small crank pin; and in Messrs. Easton's engines there was a heavy geared wheel, serving as a fly-wheel, and having a counter weight. It may be, however, that the friction of the bevel gearing was enough to bring the whole friction between the piston and the pump up to that of your engines, and therefore I have estimated for both a pressure of 1½ lbs., as that required to run the engines *per se*, and an additional friction due to the load, as equal to one-seventh of the additional pressure on the pistons over and above 1½ per square inch. This gives a net pressure of 24 lbs. in Messrs. Easton's engines, and 94·44 horse power actually applied to drive the pump. The useful work done being equal to 67·68 horse power, this is 71⅔ per cent. of the power applied, as contrasted with 83·2 per cent. in the case of your pump. As compared with the full theoretical efficiency of 100 per cent., your pump reached 11½ per cent. nearer to this than Messrs. Easton's; and as compared

directly with Messrs. Easton's pump, yours did 16 per cent. more work in proportion to the power applied.

Should the estimate of engine friction have been too high, the efficiency of both pumps would be correspondingly less than I have calculated, but your pump would still retain the same relative advantage. The results attained may be recapitulated as follows:—

MESSRS. GWYNNE & CO'S. PUMP.

Diameter of disk, 4′ 5″.
Revolutions per minute, 200.
Lift, including friction of pipes, 20 ft 8¾ ins.
Water discharged per minute, 3·268 cubic feet.
Water discharged per minute, 91·03 tons.
Equivalent work done, 128·1 horse power.
Net power applied, 154 horse power.
Useful effect attained, 83·18 per cent.
Velocity of periphery of pump, 41·886 ft. per second.
Height corresponding to this velocity, 27·207 ft.

MESSRS. EASTON, AMOS & SON'S PUMP.

Diameter of disk, 4′ 5″.
Revolutions per minute, 124.
Lift, including friction of pipes, 7 ft. 1 in.
Water discharged per minute, 5053·64 cubic feet.
Water discharged per minute, 140·77 tons.
Equivalent work done, 67·68 horse power.
Net power applied, 94·44 horse power.
Useful effect attained, 71·66 per cent.
Velocity of periphery of pump, 28·675 ft. per second.
Height corresponding to this velocity, 12·725 feet.

Protection of Iron from Rust.

From the London Builder, No. 1059.

In course of a discussion on various subjects at the Society of Arts last week, in a Committee of Reference on Mechanics and Engineering, Mr. C. F. Varley said:—All attempts to use galvanized iron for roofs in large towns failed from the smoke attacking the galvanized metal, and tinned iron did not resist the action of smoke so well even as zinc. All the experiments he had seen of coppering iron had failed unless it was done in so expensive a manner as not to be practicable for any extended use of it. What they required was a covering of lead, or lead and antimony, put upon the iron so as to combine the stiffness and cheapness of iron with the durability of lead. Owing to the multiplicity of telegraph wires in the metropolis, danger might result from the falling of long spans of wire through their being rusted away. Col. Schaffner said the coverings of houses in some countries were of tinned iron. In America this was largely used instead of lead. In St. Petersburg and Moscow iron was mostly used, but it required frequent painting. In the telegraph service he had tried many expedients for the preservation of the wires by galvanizing and the use of linseed and other oils. He had boiled the wires in linseed oil with beneficial results; but they would decay. Mr. Varley, sen., said, if iron were heated and passed through oil, the pores were filled up, and the metal lasted a long time. Mr. Reveley mentioned that

iron heated and covered with asphaltum or mineral bitumen in the solid state had resisted a moist atmosphere for fifteen years. He had found the natural asphaltum the best, and he had not succeeded so well with liquid asphalte. With all other materials he had found the rust penetrated underneath. Mr. John Braithwaite said that the mode of arresting it adopted by his father, and which he had himself followed for the last fifty years, was by painting the iron with red lead. Painting with white lead was of no use, as the acid used in the preparation of it produced swelling effects. He had inspected a well where he had fixed an engine forty-five years ago. The rods which had been placed in this well, 200 feet deep, were painted with pure red lead; and on taking them up, he found that their weight was precisely the same as when they were put down forty-five years ago.

FRANKLIN INSTITUTE.

Proceedings of the Stated Monthly Meeting, August 20, 1863.

John Agnew, Vice President, in the Chair.

Isaac B. Garrigues, Recording Secretary.

The minutes of the last meeting were read and approved.

Donations to the Library were received from the Royal Society, the Royal Astronomical Society, the Statistical Society, and the Society of Arts, London; the Canadian Institute, Toronto, and Major L. A. Huguet-Latour, Montreal, Canada; Frederick Emmerick, Esq., Washington, D. C.

The Periodicals received in exchange for the Journal of the Institute were laid on the table.

The Treasurer's statement of the receipts and payments for the month of July was read.

The Board of Managers and Standing Committees reported their minutes.

Candidates for membership in the Institute (4) were proposed, and the candidate (1) proposed at the last meeting was duly elected.

Mr. J. E. Wootten's patent Railroad Car Spring was exhibited. This spring is composed of a number of spiral springs, each of which is about one inch in diameter, and nine inches long. Two plates of ¼-inch iron are employed for retaining the ends of the spiral springs in place. For the reception of the ends of these springs, there are circular orifices made in the plates, and these have spiral grooves cut in them of a pitch corresponding with that of the coils of the spiral springs; the latter are then screwed into their places, and are thus so firmly held at their ends, that the entire spring is equally capable of resilience under either tensile or compressive strains. The one exhibited weighs but 11 pounds, yet is capable of sustaining a load of 2400 pounds, and has an elastic range of 2½ inches.

An improved Annunciator, the invention of Andrew Rankin, of this city, was exhibited. This apparatus is very neat and simple in its

construction, and, if damaged, can be readily repaired by an ordinary workman. A similar apparatus, made in New York, was also exhibited, and, although heretofore considered one of the best devices of the kind in use, is exceedingly complex compared with Mr. Rankin's.

Prof. Fleury read the following paper on the manufacture of Iron and Steel:—

For years past I have thought to give some practical use to the many thousand tons of cinder, drawn from the puddling and reheating furnaces, which at most rolling mills are thrown away as useless, or used as an admixture with iron ores in blast furnaces, in order to increase the yield (but certainly not to improve the quality) of the iron.

Chemical analysis demonstrated that these cinders contain invariably from 25 to 50 per cent. of metallic iron, combined and mixed with sulphur, silica, lime, and alumina, forming a very peculiar brittle compound, defying the most ingenious devices of our iron masters to separate. Near the Troy and the Albany Iron Works at Troy, N. Y., many thousand tons of this puddling cinder are spread over the streets, every hundred pounds of which contains from thirty to fifty-five pounds of good iron. *After many unsuccessful attempts I have finally succeeded in extracting good cast, as well as wrought iron, and have even been so fortunate as to produce from this refuse material a good quality of cast steel.*

Two great difficulties had to be overcome. 1st. The oxides and metallic iron in these cinders are combined with silica and other substances in such a peculiar way, that, by remelting the same in the puddling, cupola, or other furnace, very little of the metallic iron can be extracted; the combination withstands even the high heat in a steel crucible. 2d. By re-working the cinder with lime alone, or with lime mixed with charcoal and clay, the product is red-short, and often red and cold-short. The *sulphur*, *silicon*, and *phosphorus* remains still combined with the iron; all my attempts to extract good neutral iron from the puddling cinder by dry admixture of lime were unsuccessful; no other means remained but to destroy or loosen the tenacious chemical combination of these substances before they were placed into the furnace.

Unslacked burnt lime possesses the peculiar property of decomposing silicates during hydration, or slacking, as it is commonly called. This can easily be demonstrated by pouring water slowly into an intimate mixture of sand and freshly burnt lime—the outside of the sand grains will yield to the lime gelatinous silica, and when dried, form with it a strong chemical combination, silicate of lime,—the base of a good mortar. Taking advantage of this fact, I mixed a proper per centage of powdered burnt lime with the fine ground cinder, and after wetting the whole with water, exposed the mixture to the drying influence of the atmosphere. The dry compound was then heated in a common puddling furnace, and treated like pig-iron. I obtained 50 per cent. of wrought iron, which however retained still some traces of sulphur, leaving the iron somewhat red-short. To extract these last traces of

sulphur, I dissolved in the water, which I used for slacking the lime, a small per centage of a chlorine salt, and my expectations were thoroughly realized. *The process is also applicable to the working of silicious ores*, and can be performed in the puddling, cupola, or blast furnace. The preparation of the cinder, cost of lime, salt, &c., does not exceed $2 per ton, and if properly worked, the result is invariably a good quality of iron. Patents for this improvement have been obtained both in this country and in Europe.

Mr. Fleury also made the following remarks:

Mr. Frederick M. Ruschhaupt, an able practical chemist of Berlin, Prussia, has recently invented a new explosive compound, which is neither corrosive nor poisonous, has a greater expansive force than the now universally used fulminate of mercury, and which must, when its merits are known, be adopted as a substitute for all fulminating powders now in use. No phosphorus, sulphur, mercury, or other corrosive or poisonous ingredients enter into this compound, and therefore it is neither unhealthy to work nor dangerous to handle, and yet it will explode at the slightest stroke of the hammer arranged for exploding it. The ingredients of which it is composed can be transported separately, and may be readily mixed by a simple mechanical arrangement; when mixed its explosive properties are complete, and the compound is then ready for ignition.

The preparation of the fulminate of mercury is exceedingly dangerous to handle, the smallest particle exploding at a slight friction. During the last few years many families have been thrown into deep gloom by the havoc to life and limb occasioned by its numerous and unaccounted-for explosions. And frequent as these explosions have been, a greater evil is attendant upon its preparation, viz: the workmen engaged in its manufacture and those employed to fill percussion caps, shells, &c., with it, in a very short time become affected with sores on their hands, nose, ears, and in their eyes, which baffle medical skill to alleviate; while others inhale its poisonous dust, and their lungs become affected thereby, their constitutions impaired, and premature death is the result.

Of a similar dangerous nature is phosphorus.

Mr. Ruschhaupt's explosive compound has none of the disadvantages attendant upon the working of the ordinary fulminates; its ingredients, as before stated, may be transported separately (and which while separated are non-explosive), and can readily be mixed and filled into caps and shells with perfect safety, as no poisonous ingredients enter into its composition. Caps filled with this compound are not corroded, nor are the nipples of guns oxidized by the use of caps charged with this powder. This powder is made at much less cost than any of the ordinary fulminates.

Mr. Ruschhaupt has covered his invention by patent in the United States, and is on his way to Europe to secure patents there. Papers and necessary information relating to it, are left with John G. Kershaw, Esq., Attorney, No. 324 Chestnut Street.